Technical Report 2010-01

Principles for Strategic Conservation and Restoration

Prepared in support of the Puget Sound Nearshore Ecosystem Restoration Project

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EXECUTIVE SUMMARY

Purpose

The purpose of this document is to summarize principles of landscape ecology and conservation biology that are applicable to the conservation and restoration of nearshore ecosystems in the Puget Sound. The principles are intended to guide the prioritization of conservation and restoration sites and actions by the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP). Potential lists of restoration sites were identified from the Change Analysis data, using a process of Strategic Needs Assessment. PSNERP's mission and goals center on restoring large-scale ecosystem processes using local actions informed by a landscape-scale perspective. This report should be viewed in conjunction with three other PSNERP products: the conceptual model (Simenstad et al. 2006), guidance document (Fresh et al. 2004), and guiding restoration principles (Goetz et al. 2004). These documents provide the framework for the PSNERP restoration plan.

Methods

The principles in this report were drawn from a scientific literature review of landscape ecology and conservation biology. The review focused on literature related to the selection of sites for the conservation and restoration of ecosystems. Principles were chosen for inclusion based on frequency and credibility in the literature, and relevance to PSNERP's large-scale, process-based ecosystem approach. The PSNERP Nearshore Science Team (NST) and a designated Work Group evaluated the consistency of the principles with current scientific knowledge and applicability to the Puget Sound. The scientific literature comprised books, peer-reviewed documents, and agency 'grey' literature recommended by members of NST, the Work Group, other knowledgeable and interested individuals, and results from the Washington State Library and Google Scholar internet search engines.

Results

Eleven principles were derived from the literature and have been organized into three hierarchical scales to provide context. They are listed by relative importance in landscape ecology and conservation biology but their application is flexible. The principles are tailored towards PSNERP's goals and objectives, and are therefore restoration focused; however they are also applicable to conservation actions. While a few of the principles can be applied explicitly, most are conceptual and require further evaluation to ensure appropriate application.

Principles

Overarching Principles

Conserving intact ecosystems is the most effective method to maintain ecosystem functioning.

Conservation is an easier, more successful and cost-effective method than restoration to maintain ecosystem integrity. To achieve a net gain in healthy ecosystems, restoration must be combined with conservation. Priority should be given to intact areas that contain large, interconnected systems, regions with low development and natural shorelines, and that support important ecological components or are vulnerable to human activities.

A large-scale restoration plan should apply an ecosystem approach at the landscape level.

When addressing resource degradation and loss over large areas, the ecosystem approach has become the accepted restoration framework. It recognizes that spatial and temporal dynamics are critical components of a functioning ecosystem; thus conservation targets should link population dynamic processes that support them in particular geographic locations. An ecosystem approach at the landscape-scale also examines the cumulative effects of human activities in space and time. This is critical to achieving integrated resource management, because so many landscapes are dominated by mosaics of human development.

Restoring physical processes promotes ecosystem resilience.

Ecosystems are the manifestation of complex interactions among geomorphic, hydrologic, and biotic processes. These interactions act on the historic characteristics of the system, and affect the flow of energy, material, and biota across the landscape. The key to successful restoration is ensuring that the physical, ecosystem-forming processes that maintain landscape structure are restored to their natural spatial and temporal scales. In the nearshore environment, restoration efforts should eliminate or reduce impediments to natural processes, for instance by avoiding the stabilization of the land-water interface.

Landscape Level Principles

The natural composition and configuration of ecosystems should be restored to promote landscape resiliency.

The composition and configuration of elements in the landscape determine how physical and biological processes interact, which in turn influences ecosystem structure. Restoring all ecosystem types in an area is important to preserve landscape biodiversity and functioning. Ecosystems that have declined the most in size or quantity should receive high priority.

Restoring heterogeneity on multiple scales supports a more resilient landscape.

Heterogeneity is an integral landscape characteristic that can occur at a variety of spatial and temporal scales, resulting from natural variability in physical processes. It affects and is affected by the movement of material, energy, and biota between landscape elements. Heterogeneity can increase ecosystem functions, including biodiversity, and should be restored within the natural spatial and temporal range. Historic landscapes or current intact areas can be used as templates against which to measure levels of heterogeneity that can support natural communities.

The surrounding area has significant influence on the success of restoration efforts at a site.

In the coastal environment, strong linkages among ecosystems and with adjacent terrestrial systems determine the ecological dynamics within each patch as well as the patch dynamics throughout the landscape. The condition of the surrounding area can affect the long-term success of an existing restoration site. Restoration plans should recognize that actions taken in one part of the watershed will affect other parts, and should consider whether the existing processes and boundaries will support the appropriate flow of material, energy, and biota to sustain restored ecosystems. Ideally, a restoration project will be integrated into a supportive landscape and have a positive influence beyond the immediate project site.

Landscape connectivity should be restored to reduce fragmentation and facilitate the flow of energy, material, and biota between ecosystems.

The connectivity of ecosystems is particularly vital in the nearshore environment where material, energy, and biota are constantly being exchanged between ecosystems. The degree of connectivity regulates landscape linkages, enabling the persistence of species and ecological functioning at scales beyond that of an individual site. A well-connected landscape has a high likelihood of maintaining ecosystem processes and should be promoted wherever possible as opportunities will decrease as human land use and populations increase.

Site-Specific Principles

Larger patches generally encompass more ecological components than smaller patches.

All other characteristics being equal, larger patches of ecosystems tend to support more species than smaller patches by incorporating more environmental variation and habitat types. A larger patch is also more likely to incorporate key ecosystem processes such as natural disturbance regimes. However, it is important that the ecological components of a patch are also considered; smaller patches can provide different and supplemental ecological benefits to the landscape than large patches.

Rare or vulnerable species and habitats should receive high priority to preserve a region's biodiversity.

Ecosystems or species that are rare endangered, relict, or vulnerable to future threats should be given high conservation and restoration priority. Rare ecological components are essential to a region's biodiversity and may be irreplaceable. Past decline and future risk can be useful criteria to determine rarity or vulnerability.

Ecological components that exert disproportionately greater influence on the integrity of an ecosystem should receive special attention.

Special effort should be made to identify and protect processes, areas, and species that are particularly important to the maintenance of an ecosystem or landscape. Some ecological components exert a greater influence on the rest of the landscape than others, such as ecotones, keystone species or ecosystem engineers. Restoration efforts should ensure the persistence of these vital ecological components.

Cumulative impacts must be considered to accurately assess ecosystem degradation and restoration success.

To appropriately measure the level of degradation, cumulative impacts must be recognized as the number of individual disturbances may not equal the effects exerted on an ecosystem. Impacts can accumulate in myriad ways and should be assessed over large spatial and temporal scales. Alteration in biological, physical, and chemical properties often occurs simultaneously, resulting in non-linear degradation. The impacts from small site-scale stressors can accumulate into larger scale issues to the point where the functioning of an entire landscape is altered. Restoration efforts that address more than one impact can significantly increase the level of success of restoration efforts.

Analytical Tools

There is a growing number of models and tools that integrate complex variables to help us better understand and evaluate landscape condition (e.g., landscape metrics, FRAGSTATS, MARXAN). Models and tools are extremely useful when empirical studies are impractical due to resource constraints and large spatial and temporal scales. While it is important to recognize the limitations of each model and tool, they can help ensure that conservation and restoration planning efforts follow transparent and defensible processes.

Case studies

Case studies can advance scientific knowledge and provide opportunities to test new theories and concepts in the real world, serving also as a communication tool to disseminate knowledge to the rest of the scientific community. As a new discipline, landscape ecology is ripe for case studies to test developing concepts, demonstrate their usefulness in restoration, and illustrate the application of theoretical principles in real life situations. Unfortunately, very few case studies explicitly state the landscape ecology principles applied, how they were applied, or the results. Scientific evidence is needed that can support the application of landscape ecology principles and provide examples of their use; such evidence can inform future restoration programs and projects, reduce uncertainties, increase effectiveness and efficiency, and build a consensus of proven and accepted restoration techniques.

Discussion

Lessons Learned

Principles of landscape ecology and conservation biology are useful to examine the consequences of human actions in the environment both spatially, at broad and fine scales, and temporally, at long and short time frames. These principles have played a pivotal role in land management and terrestrial restoration perspectives and practices. The versatile concepts developed from these robust, interdisciplinary fields can also be applied to aquatic and marine ecology; however, differences in the physical environment and biota between marine and terrestrial ecosystems must be recognized as they result in different restoration needs. The majority of marine applications of landscape ecology and conservation biology principles have involved the design of marine reserve networks, but there is growing recognition that marine reserves alone are not enough to protect the rich biodiversity of coastal areas. While the empirical evidence is lacking in scientific literature, there are increasing conservation and restoration efforts using landscape ecology and conservation biology approaches to prioritize management actions in coastal regions. The results reported in terrestrial environments are promising and confer confidence in the application of landscape ecology in the marine environment.

Application of Principles

The benefit of applying principles rooted in landscape ecology and conservation biology is that they are relevant and adaptable to every restoration target, program, and plan. Incorporating this information into a restoration framework helps centralize efforts on a common goal that maximizes the ecological benefits. From this foundation, it is possible to develop criteria for measuring levels of compliance and for identifying or setting priorities on the most effective restoration and protection actions. Ideally, the principles would be applied as a preliminary screening tool to ensure that projects and sites with the greatest ecological benefits are considered first.

The transition from principle to criteria and metrics can be facilitated by integrating a general understanding of the principle with knowledge of the restoration target. There are a variety of methods for applying prioritization criteria. The chosen method depends on the program objectives as well as on the format of the data and any additional tools that are used.

A prioritization plan should apply criteria from all the principles to select restoration efforts that have the greatest potential for success in terms of restoring ecological benefits. The process of assigning priorities should be explicit, reliable, and logically sound to ensure results are defendable and repeatable. Documentation of all steps in the process is essential.

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Front and back cover: Skagit Valley, Washington. Photo by Courtney Greiner.

GLOSSARY

Benefits—ecosystem functions, goods, and services humans derive from natural ecosystems (Simenstad et al. 2006)

Disturbance—an event that causes a significant change from the normal pattern in an ecological system (Forman & Godron 1986)

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

Ecological flow—common daily flows and movements resulting from or involving species adaptations (e.g., surface water, groundwater, fire, animal foraging, animal dispersal) (Shachak & Pickett 1997)

Ecosystem—a community of organisms and their physical and chemical environment interacting as an ecological unit (PSNERP website)

Ecosystem engineer—organisms that directly or indirectly modulate the availability of resources to other species, by causing physical state changes in biotic or abiotic materials, thereby modifying, maintaining, and/or creating habitats (Jones et al. 1994)

Ecosystem function—any performance attribute or rate function at some level of biological organization (e.g., energy flow, detritus processing, nutrient spiraling) (NRC 1992)

Ecosystem processes—interactions among physiochemical and/or biological attributes of an ecosystem that involve changes in character of the ecosystem and its components. Processes are generally characterized as rates or patterns of change over time, and operate at various, hierarchical spatial and temporal scales (Simenstad et al. 2006)

Ecosystem structure—physical and biological structure and organization of an ecosystem. Ecosystem structure can be described at multiple scales-geomorphic organization of substrates and water bodies to vertical stratification of organisms by depth at a point in a beach-and at multiple dimensions-vertically in one dimension to 3-dimensions (Simenstad et al. 2006)

Ecotone—a zone of transition between adjacent ecological systems, having a set of characteristics uniquely defined by space and time scales and by the strength of the interactions between adjacent ecological systems (Naiman & Décamps 1990)

Edge—an outer band of a patch that has an environment significantly different from the interior of the patch (Forman and Godron 1986)

Fragmentation—the division of a formerly continuous natural landscape into smaller natural units that are isolated from each other (Clewell & Anderson 2007)

Habitat—the physical, biological, and chemical characteristics of a specific unit of the environment occupied by a specific plant or animal (Fresh et al. 2004)

Heterogeneity—the composition of parts of different kinds (Kolasa & Rollo 1991)

Irreplaceability—a fundamental measure of the conservation value of a site in terms of its potential contribution to the achievement of a reservation goal (Pressey et al. 1994); an area can be irreplaceable if it contains unique features, it contains non-unique features and the conservation goal is equal to their total remaining extent, or if the area contains occurrences of non-unique features that are sufficiently large that the goal cannot be achieved without conserving that area (Margules et al. 2002)

Keystone species—a organism whose impact on its community or ecosystem is large, and disproportionately large relative to its abundance (Power et al. 1996)

Landscape—a heterogeneous land area composed of a cluster of interacting ecosystems that is repeated in similar form throughout (Forman and Godron 1986)

Landscape change—the alteration in the structure and function of the ecological mosaic over time (Forman & Godron 1986)

Landscape function—the flows of energy, materials, and species among the component ecosystems (Forman & Godron 1986)

Landscape structure—the distribution of energy, materials, and species in relation to the sizes, shapes, numbers, kinds, and configurations of landscape elements or ecosystems (Forman & Godron 1986)

Large-scale—spatial resolution perceived or considered over a large area (e.g., watershed, region, landscape)

Matrix—the most extensive and most connected landscape element type present, which plays the dominant role in landscape functioning; also a landscape element surrounding a patch (Forman & Godron 1986)

Natural landscape or ecosystem—one developed by natural processes and that is self-organizing and self-maintaining (SER 2004)

Patch—a nonlinear surface area differing in appearance from its surroundings (Forman and Godron 1986)

Remnant patch—an area remaining from a former large landscape element and now surrounded by a disturbed area (Forman and Godron 1986)

Resilience—the ability of an ecosystem to regain structural and functional attributes that have suffered harm from stress or disturbance (SER 2004)

Restoration—return of an ecosystem to a close approximation of its condition prior to disturbance in terms of structure and function (NRC 1992)

Restoration success—successful restoration efforts should restore the following attributes to an ecosystem—similar diversity and community structure in comparison with reference sites; presence of indigenous species; presence of functional groups necessary for long-term stability; capacity of the physical environment to sustain reproducing populations; normal functioning; integration with the landscape; elimination of potential threats; resilience to natural disturbances; and self-sustainability (SER 2004)

Scale—the level of spatial resolution perceived or considered (Forman & Godron 1986)

Stressor—an external process or action that exerts stress on a biotic or abiotic component (SER 2004)

INTRODUCTION

Purpose

The purpose of this document is to summarize conservation and restoration strategy principles that are applicable to nearshore landscapes. Principles were derived from peer-reviewed scientific literature and technical reports on landscape ecology and conservation biology. They are intended to help guide the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP) prioritization of conservation and restoration sites and actions that have been identified from the Change Analysis data by a Strategic Needs Assessment.

PSNERP Background

The Puget Sound Nearshore Ecosystem Restoration Project is a large-scale, ecosystem based restoration project working to recover a significant degree of functions that have been lost in the Puget Sound basin since European settlement. The key focus of the project is the restoration of natural ecosystem processes that create and maintain nearshore structure and function. PSNERP was initiated in 2001 as a General Investigation Feasibility Study through a cost-sharing agreement between the Washington Department of Fish and Wildlife and the U.S. Army Corps of Engineers. After receiving strong initial support and interest, PSNERP expanded to incorporate the participation and contribution from U.S. Fish and Wildlife Service, U.S. Geological Survey, National Marine Fisheries Service, U.S. Environmental Protection Agency, U.S. Navy, nine state agencies, tribes, local governments, nongovernmental organizations, ports, the shellfish industry, and private citizens, to support the completion of the General Investigation Feasibility Study. The mission of PSNERP is to “restore and protect the nearshore habitat of Puget Sound for the benefit of the biological resources and the integrity of the ecosystem, and the people that use these resources, including the functions and natural processes of the basin” (PSNERP website).

The goals proposed to guide the program include (PSNERP 2004):

1. Protect and/or restore natural processes that create and maintain Puget Sound nearshore ecosystems, and
2. Protect and/or restore ecosystem functions and structures that support valued ecosystem components.

PSNERP is currently in the feasibility study phase, evaluating factors that are degrading the health of the Puget Sound nearshore ecosystems. The study will formulate, evaluate, and screen potential solutions to identified problems and recommend a series of restoration actions and projects (PSNERP website). To assess the extent of degradation in the basin, the PSNERP Nearshore Science Team (NST) compiled spatially-explicit data from a variety of sources to create the Change Analysis dataset. The data compare the shoreline composition, potential anthropogenic stressors, and land-use in the mid-late 1800s with current conditions (circa 2004-2006). PSNERP created the Strategic Needs Assessment Team (SNAT) to use the Change Analysis data to develop conservation and restoration portfolios, inform stakeholders, and guide the General Investigation Feasibility Study.

Content & Scope

There are many lists of stressors, sites, and types of projects targeted for restoration to improve ecosystem function and stability. However, there is no agreed-upon method for choosing among these lists in a way that will more effectively and efficiently help achieve the goals of a restoration program. Without the guidance of ecological theory and principles, sites and actions may be chosen for reasons of convenience or logistics rather than strategically, for optimal functioning of the broader ecosystem and landscape. Project selection is a subjective exercise but should be based on the recognition of the relationships between the spatial and temporal scale of physical processes and the characteristics of species, populations, communities, and ecosystems of concern (Carr et al. 2003). To help guide such selection of projects for PSNERP, this document provides a series of broad strategic conservation and restoration principles drawn from a foundation of concepts from empirical and theoretical landscape ecology and conservation biology. Although fine-scale principles would be useful as well, the complexity and uniqueness of the conditions in the landscape, constraints in timing, opportunities and enabling conditions, as well as varying considerations of ecological, economic, and social objectives in restoration plans, make fine-scale generalizations difficult to develop. Currently, fine-scale principles are absent in scientific literature.

The variability in the empirical evidence supporting the principles reflects the scientific approach of large-scale disciplines. Logistical, statistical, and ethical complications arising from traditional scientific experimentation on a complex subject, like a landscape (Noon & Dale 2002, Wiens 2002, Megrey et al. 2009), require alternative approaches that link observable phenomena to first principles grounded in robust background theory (e.g. thermodynamics, movement of matter, gravity) (Forman 1995a,b). The application of experimental model systems, simulation models, quasi-experiments, and observational, retrospective and BACI (Before and After Control/Impact) studies have been successful in building a revolutionary scientific field. Landscape ecology has brought about a paradigm shift in the perception of the environment from consisting of homogeneous, stable, and closed ecological systems that are scale-immune to open, spatially and temporally variable systems that are scale-dependent (Wiens 2002). It has developed concepts rooted in first principles that are germane to human and environmental sustainability (Noon & Dale 2002).

To provide additional support for the prioritization process, this document also introduces a few analytical tools and five case studies that illustrate various ways in which to apply the principles and tools. The report should be viewed in conjunction with three other PSNERP products: the conceptual model (Simenstad et al. 2006), guidance document (Fresh et al. 2004), and guiding restoration principles (Goetz et al. 2004). These documents provide the framework for the PSNERP restoration approach, including management measures, utilization of the best available science and the Precautionary Principle, implementation of adaptive management and long-term monitoring, and the identification of valued ecosystem components. This document strictly focuses on the prioritization process of conservation and restoration sites. It should be incorporated into a restoration framework that includes the above components that are essential to a successful restoration plan.

Approach

Landscape Ecology

Landscape ecology is a recent interdisciplinary field, integrating geography, biogeography, land-use planning, landscape architecture, ecology, wildlife biology, and landscape history. Each discipline has concepts, theories and models that together contribute to a more comprehensive understanding of human interactions with the environment at broad spatial and temporal scales (Naveh & Lieberman 1994, Farina 2000, Wiens 2002). Landscape ecology studies the causes and consequences of the configuration and composition of landscape elements (Forman & Godron 1986) at the ‘human scale’ (Wiens 2002), focusing on the structure, function, and change of landscape mosaics that are composed of patches, corridors, and a background matrix (Forman & Godron 1986). By using a large spatial scale, landscape ecology recognizes complex interactions among mosaic elements and allows the connections between structure, function, and processes to be examined spatially and temporally (Forman & Godron 1986, Swanson et al. 1988). Landscape ecology is especially important for restoration since the configuration and composition of the landscape influences the flow of material, energy, and biota, and therefore the overall functioning of an ecosystem (Swanson et al. 1988, Baker 1992, Forman 1995b, Pickett & Cadenasso 1995, Bell et al. 1997, Ehrenfeld & Toth 1997, Farina 2000, Fuerstenberg et al. 2002, Wiens et al. 2002, Roberts et al. 2003a,b, Lourie & Vincent 2004). Since land alteration for human use is a primary cause for habitat and species declines (Dale et al. 2000), it is imperative that those involved in land management understand how changes in the landscape alter the behavior and survival of species, populations, and communities (Swanson et al. 1988, Pickett & Cadenasso 1995, Bell et al. 1997, Ehrenfeld & Toth 1997, Farina 2000, Fuerstenberg et al. 2002, Wiens et al. 2002, Roberts et al. 2003a,b, Lourie & Vincent 2004). As ecosystems are fragmented into smaller patches and experience significant losses in biodiversity, their resilience to perturbations declines and they are vulnerable to further degradation. To successfully restore ecosystem integrity, the dynamic relationships between process, structure, and function must be recognized and addressed. Landscape ecology is an appropriate field to develop strategic restoration principles that promote sustainable ecosystems, optimize ecological goods and services, and reduce the impacts of development and human land use on the environment (NRC 1992, Forman 1995b).

Species vs. Ecosystem Approaches

The majority of past restoration efforts have applied a species-based approach to preserve biodiversity (Franklin 1993). The limitations of species-based restoration arise in the amount of life history data required and the unanticipated outcomes that can result when too fine a focus is applied within a complex, dynamic system. In some cases it is not until a commercially or recreationally important species is threatened or endangered that a species-based approach is applied, at which point immediate and drastic changes in land use are often required but difficult to achieve (Noss et al. 1995). As no two species respond the same to landscape changes (Farina 2000, Lindenmayer & Fischer 2006) a species approach is generally insufficient to preserve overall biodiversity (Franklin 1993, Link 2002) and can even reduce the survival of other species in the system (Fuerstenberg et al. 2002). A multispecies approach is more practical than attempting to study every species in an ecosystem; however the aggregation of species usually results in simplifying assumptions, which can lead to misinterpretations or inappropriate actions. In general, a species-based approach does not address the interactions that occur between a suite of organisms, functions, and processes and is likely to only focus on a few obvious habitat requirements (Hansson & Angelstram 1991, Kauffman et al. 1997, Link 2002). To optimize restoration efforts, a species approach can be coupled with an ecosystem approach to protect species that may slip through the coarser filter (Noss et al. 1995) or provide extra protection for commercially or ecologically important species (Franklin 1993, Farina 2000).

In terms of restoring the ecological integrity of the landscape, an ecosystem approach is more effective and efficient (Llewellyn et al. 1996, Freemark et al. 2002). An ecosystem approach addresses the primary cause of species declines and habitat loss (Noss et al. 1995), and focuses on the ecological processes that promote the persistence of structural and biological components (Brown et al. 2001, Fuerstenberg et al. 2002, Boesch 2006) by recognizing the interactions within and between ecosystems. While it does not focus on species specific parameters it can conserve ecological components that are poorly known or unknown (Franklin 1993, Link 2002) and thus can protect species before declines are observed (Noss et al. 1995). When incorporated into a management plan, the ecosystem-based approach incorporates the best available science, applies the Precautionary Principle, and continually seeks more effective applications through adaptive management (Boesch 2006). Ecosystem-based management also highlights the dependence of economic and social well-being on ecological sustainability, promoting sustainable interactions between humans and the environment (ICES 2005, Gaydos et al. 2008).

Importance of Scale

All conservation and restoration plans should be conscious of spatial and temporal scales not only when discussing a landscape but also when applying a strategy or principle (Wiens et al. 2002). The scales at which landscape processes and characteristics are evaluated have significant implications to the recognition of ecosystem processes (Risser 1987, Turner 1989, Turner et al. 2001) and the significance of pattern-process interactions (Farina 2000, Airamé et al. 2003). For example, an ecosystem may be perceived as stable from a landscape-scale but highly variable at the local-scale (Turner 1989, Farina 2000) or homogeneous to one organism and heterogeneous to another (Meentemeyer & Box 1987, Risser 1987, Fahrig 1992, Turner et al. 1995). Spatial and temporal timing and sequencing is also critical in the execution of restoration actions as they are likely to influence the biological outcomes of a project. The species assemblage that develops may differ depending on when and where restoration stages take place (Palmer et al. 1997). When planning restoration actions, the scale of analysis and application should be based on the appropriate natural boundaries of the restoration target (Risser 1987, Freemark et al. 2002), including the physical processes that influence it, and consider possible effects that may occur at larger and smaller scales; changes at one ecological level are not isolated from other levels (King 1993, Forman 1995a, Fuerstenberg et al. 2002). For effective and efficient restoration efforts, it is important to clearly articulate the scale at which actions and principles are being applied (Mangel et al. 1996, Mayer & Rietkerk 2004).

Methods

The method used to generate the principles in this report consisted of a literature review of landscape ecology and conservation biology. The review focused on concepts and principles that relate to the selection of sites for the conservation and restoration of ecosystems. Principles were chosen for inclusion based on frequency and credibility in the literature, and relevance to PSNERP’s large-scale, process-based ecosystem approach.

The principles listed in this report were reviewed by NST and a designated Work Group. Both groups, each composed of expert scientists from local universities and government and non-governmental organizations, were asked to evaluate the consistency of the principles with current scientific knowledge and applicability to the Puget Sound. The scientific literature comprised books, peer-reviewed documents, and agency ‘grey’ literature recommended by members of NST and the Work Group, other knowledgeable and interested individuals, and results from the Washington State Library and Google Scholar internet search engines. In all, 213 references were reviewed. Of those, 157 are cited in this document. Lists of reviewed and cited literature are provided at the end of the document.

Search parameters included combinations of the following terms: landscape ecology, conservation biology, restoration ecology, restoration, conservation, principles, case studies, ecosystem, processes, prioritization, criteria, large-scale, nearshore, coastal, terrestrial, watershed. All terms are included in a glossary at the beginning of the document.

PRINCIPLES

The complexity of a landscape is mirrored in the following principles. Some are clearly complementary while others may seem contradictory. Reexamining restoration objectives and the scale at which principles are applied should aid in interpretation and resolve any apparent contradictions. While a few of the principles can be applied explicitly, the majority are conceptual and require further elaboration or specific information concerning the landscape in question. They have been organized into three hierarchical scales to provide context and are listed by relative importance in landscape ecology and conservation biology, but their application is flexible. Since the principles are intended for PSNERP, they follow the program assumption that conservation actions are assessed prior to and separately from restoration actions. This assumption results in a restoration-focused program and set of principles. However, the concepts are also applicable to conservation actions and are at times integrated into the text although not explicitly included in the heading.

Overarching Principles

Conserving intact ecosystems is the most effective method to maintain ecosystem functioning.

Conserving intact ecosystems from future threats should be a high priority for any restoration plan (NRC 1992, Kauffman et al. 1997, Hoctor et al. 2000, Roni et al. 2002). Restoration efforts cannot keep pace with the rate healthy estuarine ecosystems are lost each year (RAE-ERF 1999), nor guarantee the return of ecosystem functioning and services (SER 2004, MEA 2005). To achieve a net gain in healthy ecosystems, restoration must be combined with conservation (RAE-ERF 1999). Conservation is an easier, more successful and cost-effective method to maintain ecosystem integrity (Kauffman et al. 1997, Hobbs 2002, Roni et al. 2002, Beechie et al. 2003, May & Peterson 2003) than are attempts to recover components of degraded systems (Young 2000). Allowing the continued operation of natural processes will provide diverse landscapes with heterogeneous niches for wildlife (NRC 1992) and greater ecosystem functioning (Odum 1969). Intact ecosystems can also be used as reference sites and sources of native biota for reestablishment in nearby areas (Kauffman et al. 1997). Conservation efforts should focus on large, interconnected systems (Noss 1992), regions with low development and natural shorelines (May & Peterson 2003, Bilkovic & Roggero 2008), and ecosystems that support important ecological components (Hansson & Angelstram 1991, Llewellyn et al. 1996) or are vulnerable to human activities (Roberts et al. 2003a). Ensuring that these intact systems are protected from future threats and are allowed to continue to adapt to environmental changes is imperative to the long-term functioning of the landscape (Naveh 1987, Poiani et al. 2000, May & Peterson 2003, Peterson & Lowe 2009).

A large-scale restoration plan should apply an ecosystem approach at the landscape level.

An effective restoration strategy examines targets at spatial and temporal scales that include the natural boundaries of the driving processes (Meentemeyer and Box 1987, Mayer 2004). It applies a comprehensive (NRC 1992) iterative approach that starts with a coarse filter examining landscape configuration, processes, components and interactions and moves progressively to finer scales (Mangel et al. 1996, Poiani et al. 2000, Noss & Scott 1997). When addressing resource degradation and loss over large areas, the ecosystem approach has become the accepted restoration method (NRC 1992, Crow & Gustafson 1997, RAE-ERF 1999, PEW 2003, Boesch 2006, Doyle & Drew 2008). It recognizes that all ecosystems in a landscape are interrelated, and that energy and material flow within different levels of an ecosystem as well as between ecosystems. By aiming to restore ecosystem integrity, the ecosystem approach can protect entire habitats and communities of species effectively and efficiently (Noss et al. 1995, Noss et al. 1997). Applying this approach to a broader spatial scale, like a region or landscape, inherently recognizes ecological processes and interactions at longer temporal scales (Forman 1995a). This is an important perspective when strategizing restoration efforts, because landscape patterns and processes at these broader scales greatly influence processes at finer scales (Crow & Gustafson 1997, Bennett 1999, Noon & Dale 2002). An ecosystem approach at the landscape scale is also capable of examining the cumulative effects of human activities and land use in space and time, which is critical to practicing integrated resource management (Crow & Gustafson 1997, Pearlman & Milder 2005, Peterson & Lowe 2009), as the majority of landscape mosaics are dominated by human development (Bennett 1999). A landscape perspective does not negate the consideration of smaller components of ecological systems (Noon & Dale 2002) nor the application of additional restoration approaches that address targets which may not have received sufficient attention (Noss et al. 1995). The application of an ecosystem-based approach at the landscape level simply forces the recognition of spatial and temporal dynamics. It expands the view of appropriate conservation targets by linking population dynamics and species conservation to their necessary supportive processes and geographic locations, increasing the likelihood of restoring self-sustaining ecosystems (NRC 1992) and the efficiency of land management (Farina 2000).

Restoring physical processes promotes ecosystem resilience.

Ecosystems are the manifestation of complex interactions (Lourie & Vincent 2004) between geomorphic, hydrologic, and biotic processes (Swanson et al. 1988, Kauffman et al. 1997) that act on the historic characteristics of the system over space and time, and affect the flow of energy and material across the landscape (Fuerstenberg et al. 2002). The structural characteristics that result have significant implications for the biotic community and overall ecosystem functioning (Day et al. 1989, Fuerstenberg et al. 2002, Roni et al. 2002, Guerry 2005). Ensuring that the physical, ecosystem-forming processes that shape and maintain landscape structure are restored to their natural spatial and temporal scales is the key to successful restoration (Zonneveld & Forman 1990, Mangel et al. 1996, Williams & Faber 2001, Fuerstenberg et al. 2002, Simenstad & Bottom 2004, Noss & Scott 1997). Simply restoring landscape structure without addressing the processes that sustain it does not constitute restoration (NRC 1992).

Hydrologic and geomorphic processes are drivers of the structure and function of most ecosystems, especially in the nearshore environment, distributing material and biota across the landscape (Farina 2000, Callaway 2001). The restoration of coastal ecosystems necessitates the reestablishment of natural regimes of both types of processes to maintain the composition and configuration of the landscape and allow the continued evolution of shoreforms (Swanson et al. 1988, NRC 1992, Schneider et al. 2002). These regimes are coupled with natural disturbance regimes that influence patch structure and spatial arrangement, directly affecting heterogeneity and species dynamics (Turner et al. 1995, Cissel et al. 1999, Farina 2000, Fuerstenberg et al. 2002). Many coastal ecosystems and species have evolved under chronic disturbances (Sousa 1985, Dramstad et al. 1996); for example, many floodplain flora species require regular cycles of scouring by water and deposition of sediments in order to reproduce (Farina 2000). If the disturbance regime is modified or curtailed ecological processes may be inhibited and result in rapid degradation of the ecosystem (Kauffman et al. 1997, Farina 2000, Groffman et al. 2006).

In the nearshore environment, restoration efforts should eliminate or reduce impediments and restrictions to natural processes (Nordstrom & Jackson 2005) and avoid the stabilization of the land-water interface (Schneider et al. 2002). The suppression of physical processes can lead to changes in the structure of the landscape (Farina 2000) and constrain the ability of the ecosystem to maintain suitable habitat and populations (Fuerstenberg et al 2002). This is a primary concern for ecosystem integrity due to the intricate interactions between abiotic and biotic components (Odum 1969, Dame 1996, Noss et al. 1997). For example, dense beds of bivalves can regulate environmental conditions (i.e., sediment deposition and accumulation, local topographic complexity, hydrographic conditions), which not only influence their own growth, recruitment and survival, but also provide microhabitats for other organisms increasing local biodiversity (Dame 1996, Lenihan et al. 1999). Restoration efforts need to be aware of these intricate interactions; ensuring that the underlying physical processes are restored at their natural spatial and temporal scales will increase the ability of the ecosystem to recover from future perturbations (Naveh 1987, Farina 2000, Gunderson et al. 2002, Wiens et al. 2002, Lourie & Vincent 2004).

Landscape Level Principles

The natural composition and configuration of ecosystems should be restored to promote landscape resiliency.

The composition and configuration of elements in the landscape determine the ecological flow which in turn influences the structure (Forman & Godron 1986, 1991, Forman 1995a,b, Pickett & Cadenasso 1995, Turner 1995, Farina 2000, Fuerstenberg et al. 2002, Wiens et al. 2002). Alterations can have profound consequences on the flux of processes across the landscape (Noss et al. 1995, Pickett & Cadenasso 1995, Turner et al. 1995, Day & Roff 2000). Significant loss of an ecosystem, especially one that was once-dominant or provides essential habitat, threatens the survival of populations and can result in the loss of dependent species (Hansson 1997). A minimum number of habitat sites are required to maintain viable populations of organisms. Loss of these favorable sites to human land conversion and climate change has led to the decline in species that have evolved to find these regionally scattered sites (NRC 1992). Therefore, restoring all ecosystem types across their natural geographic range is critical to the recovery of landscape biodiversity and functioning (Day & Roff 2000, Farina 2000, Margules & Pressey 2000, Roberts et al. 2003a, Bonn & Gaston 2005). Conserving ecosystem representation and redundancy can protect species persistence (Noss & Cooperrider 1994, Pressey et al. 1996, Schneider et al. 2002, Carr et al. 2003, Lawler et al. 2003), especially for species that carry out their life cycle over several types of ecosystems (Farina 2000, Fuerstenberg et al. 2002, Schneider et al. 2002, Partyka & Peterson 2008). To integrate ecosystem representation and conservation status, ecosystems that have declined the most in size or quantity should receive high priority (Noss et al. 1995, Palik 2000).

Restoring heterogeneity on multiple scales supports a more resilient landscape.

Landscape heterogeneity can occur at a variety of spatial and temporal scales and is the result of natural variability in physical and biological processes (Forman 1995a, Ewel 1997, Fuerstenberg et al. 2002, Wiens et al. 2002). It affects and is affected by the movement of material, energy, and biota between landscape elements (Pickett & Cadenasso 1995, Dramstad et al. 1996, Ewel 1997, Fuerstenberg et al. 2002, Larkin et al. 2006). Assuming species distributions correspond to physical habitat gradients, heterogeneity can increase ecosystem biodiversity and functioning (Meyer 1997, Vivian-Smith 2001, Fischer et al. 2006) by providing a variety of potential niches; these can support a larger number of species than a more homogeneous landscape (Noss et al. 1995, Turner et al. 2001, Lambeck & Hobbs 2002, Brooks et al. 2006). A heterogeneous landscape is also more likely to include crucial habitats, such as refuges that support various life stages of organisms (NRC 1992, Ewel 1997). For example, the complex structures in subtidal ecosystems acts as a nursery, feeding ground, and refuge for a diverse assemblage of resident and migrating fish and invertebrate species (Williams & Desmond 2001). An ecosystem containing a large community of resident and rare species (MEA 2005) that perform overlapping functional roles has the ability to maintain multiple pathways for nutrient interception and transformation (Levin et al. 2001). This enhances the system’s resistance to and resilience from disturbances (Tilman & Downing 1996, Gunderson et al. 2002) increasing the long-term sustainability of ecosystem functions (Christensen 1997, Fuerstenberg et al. 2002, Brooks et al. 2006). The loss of even a few populations can have destabilizing impacts on ecological communities, and is especially troubling in the nearshore environment where effects are already being observed in a number of species due to changes in the shoreline (Hirschi 1999). It is important that heterogeneity is restored within the natural spatial and temporal range. Historic landscapes or current intact areas can be used as relative templates in which to measure levels of heterogeneity that can support native species assemblages (Vivian-Smith 2001, Roberts et al. 2003b). Restoration efforts should focus on scales of heterogeneity that will influence key ecological processes and accelerate ecosystem development (Vivian-Smith 1992).

The surrounding area has significant influence on the success of restoration efforts at a site.

In the nearshore environment, strong linkages among ecosystems and with adjacent terrestrial systems (Mangel et al. 1996, Hawkins et al. 2002, MEA 2005, Fuerstenberg et al. 2002) determine the ecological dynamics and characteristics within each patch (Zonneveld & Forman 1990, Wiens 1997, 2002) and control patch dynamics throughout the landscape (Pickett 1995). The position of an ecosystem and the flux and magnitude in the flow of material, energy, and biota from the surrounding landscape are significant drivers in that system's properties and function (Turner 1995, Wiens 1995, 1997, Christensen et al. 1996, Mangel et al. 1996, Farina 2000, Fuerstenberg et al. 2002). An example of interactions that occur laterally between ecosystems is illustrated when the construction of a bulkhead inhibits sediment transport, which modifies the sediment composition of the downdrift beach and reduces its ability to support spawning forage fish (Hirschi 1999). Interactions also occur vertically across the land-water interface, for instance when changes in the composition of a watershed's land cover alters the hydrologic regime and thereby the structure and function of freshwater wetlands (Fuerstenberg et al. 2002, MEA 2005). The degree of influence that the surrounding area exerts on a patch relates to its proximity, increasing as distance decreases (Meentemeyer & Box 1987, Forman 1995a, Crow & Gustafson 1997), to its relative size in relation to the patch, and to the boundary characteristics (Wiens et al. 1997). Thus, the location of a restoration site in the landscape can have huge implications on the success of a project (Bell et al. 1998, Palik et al. 2000, Beck et al. 2001, Partyka & Peterson 2008).

The condition of adjacent sites can also affect the long-term success of an existing or potential restoration site (Wiens 1995, Hawkins et al. 2002, Wiens et al. 2002). Restoration of a salt marsh in close proximity to an existing marsh or subtidal seagrass can accelerate the development of infaunal communities (Sacco et al. 1994). Conversely, the presence of a degraded environment surrounding a restored or healthy site can reduce the function and biodiversity within the intact patch, especially when the area is experiencing intense anthropogenic modifications (Hansen & DeFries 2007, Peterson & Lowe 2009). The surrounding landscape can also be affected by a local restoration project (NRC 1992, Dale et al. 2000). Restoration plans should acknowledge these interactions in the landscape. To optimize restoration efforts, the surrounding area should be assessed to determine whether the existing processes and boundaries will support the necessary flow of material, energy, and biota to sustain the structure and function of a restored ecosystem (Callaway 2001, Fuerstenberg et al. 2002). Ideally, a restoration project will be integrated into a supportive landscape and have a positive influence beyond the immediate project site (NRC 1992, Huxel & Hastings 1999).

Landscape connectivity should be restored to reduce fragmentation and facilitate the flow of energy, material, and biota between ecosystems.

The openness and coupling of ecosystems is particularly vital in the nearshore environment where material, energy, and biota are constantly being exchanged between terrestrial, shoreline, and pelagic ecosystems (Meyer 1997, MEA 2005, Stoms et al. 2005, Megrey et al. 2009). The degree of connectivity regulates the frequency, magnitude, and direction of transfer (Meyer 1997, Wiens 1997, Williams & Faber 2001) enabling the persistence of species (Turner 1989) and ecological functioning at scales beyond that of an individual site (Forman 1995a, Brooks et al. 2006, Roberts et al. 2003b, Gaydos et al. 2008). Connectivity plays a significant role in coastal environments due to the large size and volume of the sea, the continuity of habitats, the presence of currents, and the pelagic dispersal of organisms (Lourie & Vincent 2004). In human-dominated areas, high levels of fragmentation weaken the connectivity between ecosystems (Farina 2000).

Fragmentation is a dynamic process that produces a variety of effects on the structure and function of the landscape. These include decreasing the total remaining habitat, disproportionately reducing interior habitat (Dramstad et al. 1996), isolating remaining fragments (Farina 2000) and increasing the amount of edge habitat (Bennett 1999, Young 2000, Lindenmayer & Fischer 2006). Although the specific effects on biota depend on the scale at which an individual or species perceives and moves within the environment, fragmentation can alter individual species behavior and overall assemblages (Eggleston et al. 1998, Bennett 1999, Harrison & Bruna 1999). Fragmentation is generally acknowledged as one of the most severe processes responsible for depressing biodiversity and accelerating local and global extinction of biota (Farina 2000). When relatively minor, fragmentation can increase the heterogeneity of the landscape and can promote biodiversity and recolonization by increasing edge to interior ratio (Forman & Godron 1986, Dramstad et al. 1996, Young 2000); however, the effects typically do not support native species. Altering the processes and characteristics of the patch in general alters the physical environment and ecological flow, which can lead to changes in species assemblages and loss of biota (Sisk & Haddad 2002, Layman et al. 2004). In particular, the shift in habitat ratio weakens the resilience of interior species, which are usually the targets for conservation (Forman & Godron 1986, Turner et al. 2001), by reducing their diversity, decreasing their population size, and increasing opportunities for invasive species to colonize (Dramstad et al. 1996, Harrison & Bruna 1999, Farina 2000). Fragmentation also reduces the carrying capacity of a patch (Harrison & Bruna 1999, Sierra et al. 2002), thus increasing patch dependence on adjacent sites to supply resources and isolating populations making them more susceptible to extinction (Hansson & Angelstram 1991, Christensen et al. 1996, Dramstad et al. 1996, Noss et al. 1997, Bennett 1999, Farina 2000, Lindenmayer & Fischer 2006). Once a patch is isolated it may continue to degrade and lose species (Bennett 1999, Margules & Pressey 2000). As long as fragmentation continues, the presence of poor quality ecosystems will accumulate over time and space (Peterson & Lowe 2009).

Projects that restore connectivity should receive high priority when they promote ecological processes at their natural spatial and temporal scales, thus ultimately maintaining integrity (Lambeck & Hobbs 2002, Gaydos et al. 2008). In the nearshore environment, the disruption or severing of critical links within and between drift cells can reduce the ability of local habitats to sustain species (Hirischi 1999, Carr et al. 2003). Organism dispersal is especially dependent on connectivity as many local populations are formed from larvae dispersed from distant populations (Gaines & Roughgarden 1985, Carr et al. 2003, Shanks et al. 2003). Some species require a variety of habitats to grow and mature (Farina 2000, Lindenmayer & Fischer 2006, Megrey et al. 2009, Peterson & Lowe 2009). Restoration plans should ensure that intact patches are spaced along the coast at intervals that promote larval dispersal between sites for both wide-ranging and dispersal-limited species (Lambeck & Hobbs 2002, Shanks et al. 2003). This can occur by maintaining a structurally complex matrix of native vegetation, restoring sites in close proximity, and reducing distance between intact patches by providing corridors and stepping stones of healthy patches (Dramstad et al. 1996, Fischer et al. 2006). Landscape linkages to isolated sites that contain ecologically important elements should also be identified and given high priority (Hector 2000). A well-connected landscape not only increases the survival probability of isolated populations and promotes migration between habitats (Farina 2000, Hector et al. 2001), it also has a high likelihood of maintaining ecosystem processes (Lambeck & Hobbs 2002). Since opportunities will decrease as human land use intensifies (Hoctor 2000), restoration plans should avoid further fragmentation of the landscape (Mangel et al. 1996) and strive to restore connectivity wherever possible (Noss & Cooperider 1994, Noss et al. 1995, Roni et al. 2002).

Site-Specific Principles

Larger patches generally encompass more ecological components than smaller patches.

The size of a patch affects productivity, ecological flow, and species dynamics (Forman & Godron 1986, 1991, Dramstad et al. 1996). All other characteristics being equal, larger patches of ecosystems tend to support more species than smaller patches (Fischer et al. 2006, Gaydos et al. 2008). Larger patches are perceived as having greater stability by incorporating more environmental variation. This in turn provides a greater variety of habitat types thus supporting higher species diversity and larger populations, which are more resilient to extinction (Tilman & Downing 1996, Dramstad et al. 1996, Farina 2000) than smaller patches (Harrison & Fahrig 1995, Noss et al. 1997, Farina 2000, Fuerstenberg et al. 2002, Airamé et al. 2003, Lindenmayer & Fischer 2006). By increasing patch size, the probability of including key organisms and population sources also increases (Noss et al. 1997). Moreover, a larger patch is more likely to encompass and maintain ecosystem processes (Hansson & Angelstram 1991, Dale et al. 2000, Farina 2000, Lambeck & Hobbs 2002) like natural disturbance regimes, patch dynamics (Margules & Pressey 2000) and short-distance larval dispersal (Farina 2000, Roberts et al. 2003b). This is especially important for species that have evolved under conditions structured by natural disturbances and require a minimum dynamic area to support population viability (Pickett & White 1985). Increasing patch size can also provide a buffer against the effects of fragmentation (MEA 2005), environmental fluctuations (Airamé et al. 2003), and degrading effects that may be imposed on interior habitat (NRC 1992).

However, it is important that the ecological components of a patch are also considered along with its size (Farina 2000). Small patches can provide different and supplemental ecological benefits to large patches (Forman 1995, Dramstad et al. 1996, Fischer et al. 2006, Lindenmayer & Fischer 2006) as well as education and research opportunities in urban areas (NRC 1992). Small patches may contain uncommon or rare species that do not exist in large patches and can act as stepping stones between larger patches to enhance connectivity of the landscape (Dramstad et al. 1996). While small fragments are more susceptible to perturbations, edge effects, and external influences (Hansson & Angelstram 1991, Ewel et al. 1997, Eggleston et al. 1998, Farina 2000, Young 2000, Vivian-Smith 2001, Roberts et al. 2003b), providing buffers and maintaining essential linkages to nearby habitats can increase their resiliency (Vivian-Smith 1992, Farina 2000).

Rare or vulnerable ecosystems and species should receive high priority to preserve a region's biodiversity.

Ecosystems or species that are rare, endangered, relict, or vulnerable to future threats should be given high conservation and restoration priority (Noss et al. 1995, Farina 2000, Noss 2003, Roberts et al. 2003a,b). Rare ecological components are essential to a region's biodiversity (Dale et al. 2000) and may be irreplaceable (Roberts et al. 2003b). Many rare species are dependent on localized, unique habitats. As human land use increases, landscapes become more homogenous, typically favoring generalist species (Crow and Gustafson 1997). Further loss or fragmentation of rare ecosystems can push dependent species towards extinction (Noss et al. 1995) and may threaten the ecological functioning of the entire region (Roberts et al 2003b). Past decline and future risk can be useful criteria (Noss et al. 1995) to determine rarity or vulnerability. Ecosystems that have experienced the greatest loss in a region, like the remaining 10% of coastal wetlands in southern California (Zedler 1984 in Roberts et al. 2003b), deserve high priority. Low-diversity systems are also vulnerable to perturbations and may require protection to maintain ecosystem functioning. Since they have reduced functional redundancy due to low species diversity, the loss of a single species could result in the complete loss of a process (Roberts et al. 2003a). Highly sensitive ecosystems or species can sometimes be protected by buffers whose size, shape, and composition are suited to the task and are particularly important when the surrounding area exerts strongly negative influences (Fischer et al. 2006).

Ecological components that exert disproportionally greater influence on the integrity of an ecosystem should receive special attention.

Special effort should be made to identify and protect processes, areas, and species that are particularly important to the maintenance of an ecosystem (Mangel et al. 1996) or landscape. Some ecological components exert a greater influence than others (Palmer et al. 1997, Beck et al. 2001, Lindenmayer & Fischer 2006). Ecotones, like wetlands (Williams & Desmond 2001), marshes, and deltas, are vital components of the landscape (Schneider et al. 2002) providing services essential to sustain coastal functioning. Not only do they act as hotspots for decomposition and nutrient cycling (Farina 2000, Ewel et al. 2001, Levin et al. 2001) they also provide critical refuge in human-dominant landscapes, and support especially diverse assemblages of resident and migrating biota (Farina 2000, Levin et al. 2001, Roberts et al. 2003b, Borde et al. 2004). Their dependence on complex landscape interactions makes them highly susceptible to hydrologic and geomorphic regime modifications and necessitates attention to actions upstream and in the surrounding area (Ewel et al. 2001, Fuerstenberg et al. 2002). Other high-priority landscape components are ecosystems that support species in vulnerable life stages, are vital to the completion of a life cycle, or act as a source for resources (Roberts et al. 2003a,b).

Similarly, as species vary in their roles in an ecosystem, the changes in abundance of some are of greater consequence than others (Mangel et al. 1996) and can cause cascading effects (Dale et al. 2000). Both keystone species and ecosystem engineers are key elements to biodiversity, respectively influencing regulatory effects on ecosystems and altering the environment to support a multitude of other species (Boogert et al. 2006). A significant decline in the population of either group can impact a system in multiple ways (Hansson & Angelstram 1991, Dale et al. 2000), for example altering interspecific interactions in food webs, disrupting nutrient cycling or disturbance regimes, causing multiple species collapse, or reducing the heterogeneity of a system (Noss et al. 1995, Farina 2000, Gaydos et al. 2008). Successful restoration of such species may have strong implications for the recovery of the diversity and function of a system's assemblage (Palmer et al. 1997). Restoration efforts should ensure the persistence of these vital ecological components to promote the integrity of the ecosystem and landscape.

Cumulative impacts must be considered to accurately assess ecosystem degradation and restoration success.

To appropriately measure the level of degradation, cumulative impacts must be recognized (Sharitz 1992, Mangel et al. 1996, Williams & Faber 2001) as the number of individual disturbances may not equal the effects exerted on an ecosystem (NRC 1992, Pringle 2001). Due to the influence of physical, biotic, and anthropogenic drivers that interact at several spatial and temporal scales (deYoung et al. 2004, Megrey et al. 2009), alterations in biological, physical, and chemical properties often occur simultaneously. This results in non-linear degradation (NRC 1992) that may quickly exceed some system thresholds and cause abrupt responses to perturbations (Megrey et al. 2009). Although it is not yet known what threshold levels trigger ecosystem shifts, certain anthropogenic stressors are threatening to push entire ecosystems to irreversible collapse (Brown et al. 2001). The unprecedented magnitude and frequency of changes caused by human alterations (Turner et al. 1995) overwhelm ecosystem processes (Farina 2000) and do not allow ecosystems to adapt (Odum 1969), causing far greater impacts on ecosystems than natural disturbances (Lindenmayer & Fischer 2006). A variety of side effects can arise (Odum et al. 1987) that often damage regulatory pathways and mechanisms, thereby reducing complexity and resiliency in systems (Groffman et al. 2006). Ecosystems with low resilience are more likely to undergo dramatic shifts to states (Farina 2000, Fuerstenberg et al. 2002, Groffman et al. 2006) with reduced productivity and diversity (MEA 2005).

Cumulative impacts in hydrology caused by anthropogenic stressors (Pringle 2001) are of special concern in aquatic restoration as shifts in nearshore assemblages appear to be triggered by relatively low levels of development (Bilkovic & Roggero 2008) and alter the productivity and functioning of entire ecosystems (Peterson & Lowe 2008). Impacts can accumulate in myriad ways. Locally, the deleterious effects a bulkhead exerts on the nearshore (Kauffman et al. 1997, Spalding & Jackson 2001, Nordstrom & Jackson 2005, Bilkovic & Roggero 2008) can be magnified by the specific location on the shoreline (MacDonald et al. 1994) and the presence of upland development (Bilkovic & Roggero 2008). As more bulkheads are installed along the shoreline, the local effects can accumulate and coalesce influencing systems and drainages to the point where the functioning of an entire landscape is altered (Peterson & Lowe 2009). Impacts can also accumulate in the food web as the effects of fragmentation on nekton communities tend to reduce secondary productivity in estuarine and marine environments (Bilkovic & Roggero 2008). The effects of land alteration, especially in community composition and biogeochemical cycles, can last for decades or centuries (Dale et al. 2000). Recognizing cumulative impacts is also important in planning restoration actions. Addressing more than one impact can significantly increase the level of success of restoration efforts (Lotze et al. 2006). It is therefore essential that cumulative impacts are recognized at all spatial and temporal scales in order to understand the full magnitude of degradation and restoration in a landscape.

ANALYTICAL TOOLS

There are a growing number of tools designed to simplify and integrate complex variables to better evaluate landscapes. Such tools are extremely useful when empirical studies are impractical due to spatial and temporal scales and resource constraints. Some, like GIS and satellite imagery, have fostered the development of landscape ecology concepts while others, like FRAGSTATS, have aided in the application of those concepts. Using whole landscape, distributional, and spatial models can help predict changes in the landscape due to modifications in disturbance regimes or global climate change (Baker 1989). While it is important to recognize limitations, these tools can help ensure that conservation and restoration planning efforts follow transparent and defensible processes (Margules & Pressey 2000).

Landscape Metrics

Landscape metrics are tools for the application of landscape ecology concepts, useful for communication and ecosystem-based monitoring, planning, and decision making. Metrics can measure the arrangement of landscape elements in time and space, allowing the user to characterize the properties of a patch and quantitatively measure patch interactions. A variety of landscape metrics have been developed to describe complex processes like fragmentation and allow comparisons of alternative landscape configurations. One limitation is lack of data, but by applying metrics that are ecosystem based instead of species-based the amount of data required can be reduced. Examples of metrics include (Leitão & Ahern 2002):

Patch richness (PR)- measures the number of classes present in the landscape (PR increases when greater diversity/heterogeneity is present)
Class area proportion (CAP)- measures the proportion of each class in the landscape
Total number of patches (NP)- measures the total number of patches of a specified land use or land cover class
Proximity (PROXIM)- measures relative distance between patches of the same class and can be used as a surrogate for connectivity
Contagion (CONTAG)- measures the relative aggregation of patches of different types at the landscape scale

FRAGSTATS

FRAGSTATS is a spatial pattern analysis program that quantifies landscape structure. The program is versatile, capable of representing any spatial phenomenon. The user selects landscape metrics to quantify the areal extent and spatial distribution of patches within a landscape as well as the classification and delineation schemes. General metrics (e.g., Area, Patch Density, Size and Variability, Edge, Shape, Core Area, Nearest Neighbor, Diversity, Contagion and Interspersion Metrics) are comprised of several spatial statistics and contain their own benefits and limitations. Because composition and configuration can affect ecological processes independently and interactively, it is important to understand what aspect and scale each metric quantifies to reduce unnecessary redundancy (McGarigal & Marks 1995).

MARXAN

MARXAN is a marine reserve planning tool that creates and evaluates different networks of reserves by varying representation requirements, costs and restrictions. The software tool was derived from a set of terrestrial reserve siting programs (i.e., Spexan, SITES, and Simann) based on fundamental operations that are translatable to the marine setting. The user identifies features associated with the conservation target as well as desired characteristics and inclusion specifications. The software combines these elements with an objective function that includes cost, penalties for not achieving all targets and a spatial configuration component, then applies an optimization method to determine reserve designs. It is also possible to incorporate concepts, like irreplaceability and selection frequency, and account for uncertainty. MARXAN is most useful when areas are so large and complex that many different scenarios need to be explored (Ball & Possingham 2001).

CASE STUDIES

Case studies are invaluable tools that can advance scientific knowledge and provide opportunities to test new theories and concepts in the real world as well as provide a mechanism to disseminate knowledge to the rest of the scientific community and the public. As a relatively new discipline, landscape ecology is ripe for case studies to test developing concepts, demonstrate its usefulness in restoration, and illustrate the application of theoretical principles in real life situations. Unfortunately, there is a gap between the application of landscape ecology principles in conservation and restoration plans and the documentation of results, which may be due to the long time periods required to observe results in large-scale studies. The majority of the case studies describing the use of landscape ecology principles in restoration efforts focuses on the need to apply a large-scale ecosystem approach, the usefulness of landscape ecology, and their integration into conceptual models. Very few of the case studies explicitly state what landscape ecology principles were applied, how they were applied, or what the results were. This is a critical gap in the progression of landscape ecology and restoration efforts. It is imperative that scientific evidence can support the application of landscape ecology principles and provide examples of its use to inform future restoration programs and projects, reduce uncertainties, increase effectiveness and efficiency, and build a consensus of proven and accepted restoration techniques. The four case studies presented below illustrate the effective integration of landscape ecology concepts in restoration planning.

FRAGSTATS Application of a Multi-Scale Landscape Assessment to Predict Marbled Murrelet Habitat

Multi-scale landscape and seascape patterns associated with marbled murrelet nesting areas on the US west coast (Meyer et al. 2002)

Background

A large-scale retrospective study was conducted on the marbled murrelet (Brachyramphus marmoratus) using pre-existing data on the distribution and abundance of nesting sites to assess the importance of spatial variables in predicting habitat use across multiple spatial scales in California and southern Oregon. The extensive daily movements of the murrelet from feeding sites in coastal waters to nesting sites in old-growth forests present the ideal opportunity to assess spatial juxtaposition of habitats over a large area.

Application of Analytical Tools

Hypotheses were developed using two metrics (occupancy and abundance) at four spatial scales (old-growth patch, landscape, sub-region, and region) and two temporal scales (1985-1988 and 1991-1997). Data were assembled into GIS where land cover maps were created and overlaid with marbled murrelet data. Within the landscape-size plots, fragmentation and other spatial variables were calculated using FRAGSTATS.

Meyer et al. (2002) applied landscape metrics at four spatial scales to identify marbled murrelet habitat preferences. All four spatial scales contained variables with substantial effects on murrelet use. Regional characteristics such as fog zone, elevation, and maximum distance to the ocean were significant delimiters of the nesting range. Sub-regional characteristics (e.g., distance to productive marine habitat and sandy shores), and landscape characteristics (e.g., old-growth fragmentation) helped further predict where murrelets were likely to be found or were abundant within the newly defined nesting range. Previous studies on marbled murrelet habitat that focused on individual patch characteristics did not observe improved predictions of marbled murrelet occupancy or abundance. The results suggest that multiple spatial scales should be investigated for species that cover large areas or use spatially segregated habitat types. If broad spatial scales across large geographic regions are ignored habitat prediction may be weak or unreliable.

Conclusions

Studies of wildlife habitat could benefit from this approach of combining variables measured at vastly different spatial scales into one model. Most habitat studies model either one scale or multiple scales individually, and often cannot obtain the predictive power observed when multiple scales are studied concurrently. Spatial modeling at different scales is especially important for species that exhibit frequent and long range movements between different habitats. The proximity and quality of those habitats need to be evaluated. The results also demonstrated the importance of evaluating temporal effects. The relatively recent history of logging in the area was found to account for why some heavily fragmented old-growth forests were still observed in use. Previously it was assumed that fragmentation did not influence the use of marbled murrelet habitat. To fully understand the deleterious effects of habitat loss or fragmentation over time, this study demonstrated that long-term monitoring of habitat and animal population changes is important for long-lived species with high site fidelity.

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Landscape-Scale Restoration in the Skagit River Basin

Landscape and Watershed Scale (Apostol et al. 2006)

Background

The Skagit River Basin in northwest Washington State is the largest drainage in Puget Sound, containing more than 8,000 square kilometers of the North Cascade Mountains of Washington and British Columbia. The area supports a number of species from grizzly bears in the forested uplands to tens of thousands of shorebirds, waterfowl, and raptors in the delta and adjoining bays. Since Euro-American settlement around 1860, floodplains and tidal wetlands have been diked, drained and cleared for farming, forests have been heavily logged, railroad and road construction opened the area to mining, and five major hydroelectric dams have been installed. Highly protected federal lands in the upper basin have led to surprisingly good ecological health in the river system. However, intensive agricultural development in the Skagit delta has resulted in significant losses in habitat. Approximately 72% of historic lowland wetlands, 84% of tidal habitats, 66% of forested estuary transition zones, 68% of emergent marsh, and 75% of slough habitat has been lost.

Application of Principles

To improve the coordination and effectiveness of salmon habitat protection and restoration, 13 organizations came together in 1997 to form the Skagit Watershed Council. The Council has since grown to include 40 organizations and has been officially designated as the local lead entity for salmon recovery under State of Washington legislation. The council adheres to a landscape-scale approach, rigorously screening and prioritizing all proposals for Skagit basin habitat protection and restoration with a natural process-based scientific framework. This has resulted in effective basin-wide restoration through small-scale projects.

Three major documents that guide habitat restoration and protection efforts include:

Habitat Protection and Restoration Strategy- lays out a scientific framework for analyzing landscape processes and provides a set of procedures for screening and prioritizing actions focusing on the causes of watershed degradation. It also incorporates the Application of the Skagit Watershed Council's Strategy.

River Basin Analysis of the Skagit and Samish River Basins- identifies site-specific levels of impairment of landscape processes throughout the basin.

Strategic Approach- combines the scientific information developed in the Application with recent data on particular species to target certain project types and specific geographic areas for restoration and protection. Three principles were applied: (1) the best available information should be used to target the most biologically important areas for salmon restoration and protection, prioritizing habitats of listed and depressed salmon stocks; (2) within the identified target areas, the council should protect the highest-quality habitats first and then restore key habitats, selecting projects based on the suite of natural process impairments; (3) focus on the most cost-effective projects first in order to ensure the best and most efficient use of limited funding.

Conclusions

Since the council began reviewing and prioritizing project proposals in 2000, 51 projects have received funding totaling more than $15.9 million. The strategic framework strongly encourages restoring impaired landscape processes in upland areas rather than waiting to deal with the damages that result in downstream areas. For example, four sediment reduction projects focused on upgrading or decommissioning roads that had been identified as having high potential to cause mass wasting events and transport sediment to important aquatic habitats. Significant progress has been made in alleviating elevated sediment in the mainstream of the Skagit and major tributaries. Reconnecting isolated habitat has also been a major part of the strategic focus, in part because of a high likelihood of success. Most projects have focused on improving passage to tributary habitats. Since 1998, projects have improved fish passage to more than 25 miles of habitat and 28 fish passage restoration sites are monitored.

The success of the Skagit Watershed Council and its effective application of a process-based scientific framework in a landscape-scale approach is a model for large-scale restoration projects. The outcome of hundreds of acres of protected high-quality habitat, treatment of forest roads, and the restoration of streams, riparian forest, tidal marsh, and other ecosystems into suitable habitat for native species illustrates the efficiency and effectiveness of their strategic landscape-scale approach.

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Restoration Prioritization Framework

Lower Columbia River restoration prioritization framework (Evans et al. 2006)

Background

A decision-making tool, the Prioritization Framework, was developed for the Lower Columbia River Estuary Partnership to help identify the highest priority sites for restoration. The Prioritization Framework was based on a conceptual model stating that the physical controlling factors in a location drive the habitats that can form, and ultimately, the ecological functions that develop. The Prioritization Framework used this model to evaluate a variety of human stressors that impact these controlling factors. It is composed of three parts: (1) an overview of the concepts and description of Framework tools, (2) a Microsoft Excel workbook containing detailed data, formulas, and workflow for the actual site prioritization, and (3) a GIS database containing source and processed geospatial datasets. It also incorporates information on hydrologic connectivity and existing function into the priority screening. Specific projects or proposals are evaluated on cost, expected functional change, site, size, and predicted probability of success. The Framework provides a tiered approach through which the Estuary Partnership can screen for impacted areas, prioritize areas based on desired ecological criteria, and evaluated selected projects.

Application of Principles

One of the criteria in Tier I of the Prioritization Framework was landscape connectivity. Metrics were developed to estimate the hydrologic and physical connection of each site to other sites. The metrics were given scores of 0 to 5 to simplify the analysis. The scoring was based on percentile breaks within the data (typically 20th, 40th, 60th, 80th, 100th) with higher scores indicating a higher measured connectivity, i.e. more desirable in the context of landscape processes. The metrics included:

Site adjacency- to provide an estimate of direct physical connection to nearby sites that may be affected by restoration actions the number of other sites it shares a border with was calculated.
Diked area blockage- to calculate the potential hydrologic restoration, the number of sites impacted was calculated for each diked area polygon. The metric indicates the areas where dike removal may restore hydrology to the greatest number of sites.
Hydrologic reach connections- a rough metric of total site-to-site connectivity via waterways was calculated using a hydro line dataset. The number of sites that each hydro line contacts was summed and the totals were then summed for all of the unique hydro lines running through each site.
Site area- used to prioritize sites of a desired size within the landscape.

The Tier I criteria provided guidance on where restoration would be beneficial and feasible, indicating known stressors where successful restoration could occur. A general ranking formula (site score = [Δ function x size x success] / cost) was applied in Tier 2 to sort out the best and most viable projects.

Conclusion

The Prioritization Framework includes the essential restoration plan components and applies a landscape-scale perspective, focuses on physical processes, and provides a unique example of using landscape connectivity in a prioritization plan as well as developing relevant metrics by which to measure. While there are some limitations in the scoring method, it is a valuable example of how to reasonably group data in the absence of scientific justification for specific thresholds. The study illustrates the integration of conceptual models, best available science, and landscape ecology concepts into a strategic prioritization plan.

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Louisiana Coast Conservation and Restoration

Coast 2050: Toward a Sustainable Coastal Louisiana (Louisiana Coastal Wetlands Conservation and Restoration Task Force & Wetlands Conservation and Restoration Authority 1998)

Background

The Louisiana coastal area (LCA) contains one of the largest expanses of coastal wetlands in the contiguous U.S. and accounts for 90% of the total coastal marsh loss in the nation. Largely developed by the deltaic processes of the Mississippi River, the coastal area is composed of a diverse array of ecosystems that range from expanses of forested swamps to saline marshes and unique vegetation communities, like floating marshes and maritime forests. While the cumulative effects of both human induced and natural factors are believed to have reduced wetland conditions, the measurable increase in coastal land loss in the mid to late 1900s can be linked to human activities that fundamentally altered the deltaic processes of the coast and limited their ability to adapt to the changing environment. Due to the magnitude and variety of these human-induced changes and their interaction with natural landscape processes, the LCA Task Force and Authority decided that all of the factors contributing to coastal land loss and ecosystem degradation needed to be viewed comprehensively to fully understand how the coastal ecosystem shifted from the historical condition of net land gain to the current condition of accelerated net land loss.

Application of Principles

The restoration of the LCA is based on the reestablishment of the natural processes that created the productive wetlands. Based on ecological principles, the LCA Task Force and Authority developed a set of strategic goals from which a series of regional strategies were derived. The regional strategies were applied to the four regions, determined by hydrologic basins within the LCA, and adapted the specific conditions and characteristics of the region, as well as the opinions of the local stakeholders. A list of local and common strategies was then derived from the adapted regional strategies. The regional strategies were also sequenced by near term (1-5 years), intermediate term (6-15 years), and long term (16-50 years). The following is an example of their application in Region 1, which encompasses the Lake Pontchartrain Basin. In Region 1, the parish governments and citizens were more concerned with maintaining present habitats and current levels of productivity than making significant changes in land use.

Strategic Goals:

Maintain vertical elevation to achieve wetland sustainability

The natural, long-term productivity of Louisiana coastal wetlands has occurred because, over a large area and over time measured in centuries, these ecosystems were maintained against the natural forces such as subsidence and erosion that cause marsh loss. Self-maintenance is the most essential attribute of an ecosystem. To achieve self-maintenance in marshes, marsh elevation within the tidal frame requires vertical accumulation of sediments and vegetation growth that occur through periodic, gentle marsh flooding and drainage that promote healthy vegetation and large rates of organic production.

Maintain estuarine gradient to achieve diversity

Diversity of habitats and the consequent diversity of fish and wildlife resources is a second essential characteristic that makes the natural system so productive. A dynamic salinity gradient in each estuary is the fundamental driving force that creates natural ecosystem diversity. Significant freshwater input must occur at the upper end of each estuary and must flow seaward to grade into increasingly saline and tidally dominated flow at the gulf end of the estuary, where the system is partially contained by emergent land. With a salinity gradient comes the gradation of fresh-intermediate-brackish-saline vegetation and associated variations of fish and wildlife habitat.

Maintain exchange and interface to achieve system linkages

Ecosystem linkages are the pathways by which energy, materials, and organisms are transferred and mixed among the ecosystem components. Effective interconnections are needed to support a food chain that is diverse and highly productive. Optimal linkages require that the landforms and hydrology of the ecosystem allow efficient exchange of energy and materials between the marshes and estuaries. In turn, this is achieved by habitats that have stable edges and that are naturally interspersed with other habitats, and by a hydrologic regime that maintains the natural rhythms of the coast, including tidal cycles, storms and river floods.

Regional Strategies:

Enhance the ecosystem by using resources more efficiently

In some areas, especially those with strong and positive riverine influences, the integrity of the natural system is intact and the wetlands are considered sustainable through 2050 with little or no further intervention.

Maintain the ecosystem by addressing known risks

In some areas, the ecosystem is now thriving but is at risk of losing its sustainability by 2050. These ecosystems may be at risk from the predicted loss of adjoining wetlands, shorelines, barrier islands, or levee ridges that now provide integrity. The risks may also relate to prospective changes in existing hydrologic management. In such areas, strategies aim to reduce risks and promote hydrologic conditions that are favorable to sustainability, diversity, and exchange.

Recover the ecosystem by reversing the loss process

Large areas of the coast exist where the ecosystem has lost some of its integrity and the emergent wetlands are no longer self-maintaining. Where these areas have a platform of intact (but perhaps declining) vegetation, it is possible that the wetlands could return to self-maintaining conditions. The strategies are to recover sustainability through restoration actions that recreate the lost aspects of system integrity, reduce existing vegetation stresses, and/or stimulate vertical accumulation.

Rebuild the ecosystem by recreating new wetlands

Finally in some parts of the coast, the ecosystem has degraded to the point that virtually all of the ecosystem integrity is lost and there is no vegetative substrate upon which to recover sustainable conditions. Consequently, if emergent wetlands are desire, they will need to be newly built, as through a new delta lobe or marsh creation project. Alternatively, such areas would exist and function as an open water system.

Conclusions

The Coast 2050 is an impressive example of how broad restoration strategies based in ecological principles can be incorporated into a large-scale plan and then broken down and applied to regional and local scales to create ecologically sustaining results that are integrated with socioeconomic criteria. Implementing the regional ecosystem strategies will achieve the overarching goal of Coast 2050, to sustain a coastal ecosystem that supports and protects the economy and culture of southern LA and contributes greatly to the economy and well-being of the nation. In Region 1, implementing all of the regional strategies is estimated to prevent approximately 74% of the marsh loss across the entire region by

2050, thereby saving 33,500 acres of marsh, restoring the highest practicable acreage given the constraints placed on Mississippi River diversions by local interests.

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DISCUSSION

Lessons Learned

Ecosystems are dynamic entities comprising a plethora of physical and biological components that interact in a complex web, providing goods and services essential to sustaining life. Landscape ecology provides a useful approach to examine the consequences of human actions in the environment both spatially, at broad and fine scales, and temporally, at long and short time frames. Understanding how human actions impact the environment and how those impacts might persist in the landscape (Dale et al. 2000) can promote strategic sustainable actions. Landscape ecology has the ability to point human land use towards a sustainable future (Forman 1995).

As a new science, there are controversies about landscape ecology and conservation biology concepts and their practical application in conservation and restoration (e.g., setting specific targets). One debate of immediate concern is the threshold for action. While no ecological component should be discounted as unnecessary, a lack of time and resources make it unrealistic to restore every degraded site. The literature suggests a range of threshold criteria from restoring sites that will be lost without immediate action (NRC 1992) to sites with the most to lose (Noss et al. 1995) to the direct avoidance of areas where external risks are too great (Roberts et al. 2003a). Until a consensus can be reached, this issue will have to be addressed on a case-by-case assessment in the context of specific goals, objectives, and resources (Noss et al. 1995). There is, however, a consensus on the pressing need for action (Browman 2004). Human effects are pervasive in the landscape (Christensen et al. 1996). Resources are being depleted at accelerating rates and human population is still increasing (Mangel et al. 1996) especially in coastal areas (Worm et al. 2006, Peterson & Lowe 2009), fisheries around the world are collapsing (Lotze et al. 2006), biodiversity is rapidly declining, pollutants are contaminating the air and water on a global scale, and the effects of climate change are just beginning to be observed (Worm et al. 2006). Action cannot be inhibited by uncertainty. There will always be limitations in human knowledge and our ability to make predictions. However, the current understanding of ecological processes and the tools and models available form a solid foundation for conservation and restoration actions, which should follow strategic plans based on general principles (Christensen et al. 1996). Uncertainty only emphasizes the need to err on the side of caution, monitor restoration efforts, and disperse results throughout the scientific community.

Landscape ecology and conservation biology have played a pivotal role in land management and restoration practices (Pearlman & Milder 2005). The new fields have experienced rapid development with research mainly occurring in terrestrial environments where they originated. However, their robust interdisciplinary roots allow concepts to be applied to aquatic and marine ecology. For decades oceanographers have been grappling with landscape-level scaling effects, and concepts of patchiness and patch dynamics have played an integral role in understanding streams, rivers, and lakes (Wiens 2002). While many of the landscape interactions are similar, there are differences between marine and terrestrial ecosystems that result in different restoration needs. For example the importance of restoring connectivity differs greatly in the two environments (Carr et al. 2003). Most species in the marine environment (e.g., benthic invertebrates, algae, coastal fishes) have very different reproductive strategies than terrestrial species, especially in their prevalence of planktonic propagules (Shanks et al. 2003); they require multiple habitat types to complete their life cycle (Guerry 2005). This greatly enhances the openness of the populations and emphasizes the need to protect connectivity, as well as the range of ecosystem types. Consequently, reserves should form a network along the coast to support sufficient organism dispersal and settlement among sites (Shanks et al. 2003) as well as the transport of material that is necessary to maintain ecosystem structure. In contrast, populations in the terrestrial environment are generally dependent on local adult fecundity, exhibit minimal immigration and limited offspring dispersal (Shanks et al. 2003). Therefore on land, connectivity is needed to link ‘hotspots’ and buffer large-scale habitat destruction (Carr et al. 2003). These needs produce a slightly different reserve design than those in the marine systems. A failure to recognize the ecosystem processes and settings that are present in a specific landscape during the application of generalized restoration principles can lead to inappropriate and ineffective actions.

The majority of marine applications of landscape ecology principles have involved the design of reserve networks. These principles have promoted the incorporation of broad spatial concepts into reserve designs and have increased confidence in the effectiveness of networks. However, there is growing recognition that reserves alone are not enough to protect the rich biodiversity that exists in coastal waters. There are increasing numbers of conservation and restoration efforts utilizing a landscape ecology approach to prioritize management actions in coastal regions. These studies are compiling data on changes observed in the landscape to examine the cumulative actions that are degrading a region. Ecological criteria are applied to rank areas on their opportunities and constraints to contribute to regional ecosystem functioning. Unfortunately, as these projects are currently in development and implementation stages, literature on results is not yet available. The results reported in terrestrial environments, however, are promising and confer confidence in the application of landscape ecology to the marine environment.

Application of Principles

The benefit of applying principles rooted in landscape ecology is that they are relevant and adaptable to every restoration target, program and plan. The principles can help organize seemingly disparate spatial and temporal scales, evaluate variables that occur at multiple levels of organization, and provide insight into the ecological roles of individual components in the environment. Incorporating this information into a strategic prioritization plan can organize resources and projects around a common goal that promotes the integrity of the entire landscape and increases the likelihood success. Ideally, the principles would be applied as a preliminary screening or baseline assessment to ensure that projects and sites with the greatest ecological benefits are considered first. Applying ecological criteria prior to socioeconomic criteria can prevent the selection of sites that have little biological value or fail to meet the restoration objectives (Roberts et al. 2003a,b, Guerry 2005).

Before the principles can be applied in a prioritization plan, criteria need to be formed and metrics need to be identified to measure a project’s compliance. While not covered in depth in this report, this is an essential step in the process. A large, detailed dataset may result in better informed and more reliable results but it is not required. However, an understanding of the interactions between the restoration target and landscape, identification of the stressors and their impacts on the target, and data on the historic character of the landscape are necessary. The transition from principle to criteria and metrics can be facilitated by integrating a general understanding of the principles and their concepts and the knowledge of the restoration target. Once the fundamental links have been identified, criteria and metrics will begin to emerge. In Table 1, the strategies of each principle are presented, as well as a set of general criteria and metrics. Additional criteria and metrics can be derived from the principles and adapted to a specific program or target.

There are a variety of methods in which to apply and measure prioritization criteria. The chosen method depends on the preference of the program, the format of the data and additional tools that may be used in the process. A program may also choose to add weights to certain principles or criteria that are more relevant to their objectives. To increase the reliability of the prioritization results the criteria should be quantified (e.g. sediment transport rates, hydrologic flow, or size) whenever possible. Applying thresholds to the criteria would be the ideal method; unfortunately the scientific literature lacks such consensus. The method used by Evans et al. (2006) in the Columbia River case study, in which scores were assigned based on set percentile breaks within the data, may be the most reliable and logical method until standard thresholds are developed. The data applied to Evans et al. (2006) method can range from presence, percentage, or overall count. For example, when assessing the historical loss of a restoration target, projects may be ranked by the percentage change from historic to current. Those that experience the greatest change are in the top percentile and receive a higher score than those in the next lower percentile and so on. Scores are then relative to the amount of degradation and potential ecological benefits within that region and account for natural variability and uniqueness in the landscape.

A prioritization plan should apply criteria from all the principles to select restoration efforts that have the greatest potential for success and restore the optimal amount of ecological benefits. The principles require intelligent application as they are generalizations. The utilization of socioeconomic criteria, stakeholders, and additional tools can further prioritize project lists by cost, feasibility, and risk. The overall process should be explicit, reliable, and logically sound to ensure results are defendable and repeatable. Documentation is especially critical to reduce future misapplication and promote effective methods of prioritization.

Application specific to PSNERP

Based on the program goals, available data, and Change Analysis, examples of how the principles have been or can be furthered be applied are provided below. A set of questions is also included to promote the links between the principles and the projects under consideration.

Conserving intact ecosystems is the most effective method to maintain ecosystem functioning.

The effectiveness of restoration efforts and efficient use of limited resources can increase if restoration is integrated with conservation. The Change Analysis identifies areas that are not significantly impacted by upland change and large, unimpaired areas not in public ownership that may be targeted for conservation. A Future Risk Assessment will provide information on future human development and land use in the Puget Sound and will help identify nearshore areas that are vulnerable to future threats.

> How does a project/site play a critical role in supporting an intact area?
> Is the project/site physically or ecologically connected to an intact area?
> Is the project/site adjacent to an intact area?

A large-scale restoration plan should apply an ecosystem approach at the landscape level.

The first task in PSNERP's feasibility phase is to "evaluate significant nearshore ecosystem degradation of Puget Sound" which is based on the underlying scientific assumption that "ecosystem function and performance are contingent upon landscape setting" (Goetz et al. 2004). The program illustrates the application of this principle through the Change Analysis by developing projects that address strategic needs at the scale of Puget Sound.

> Does the project address interactions between the restoration target and the landscape in which it resides?
> Is the project developed in a landscape-scale perspective?
> Does the project aim to restore ecological integrity to a scale beyond the site?

Restoring physical processes promotes ecosystem resilience.

One of the strategic guiding restoration principles of PSNERP is that "programs should focus on restoration of natural processes that create and maintain nearshore ecosystem structure and function" (Goetz et al. 2004). The structure of the Change Analysis data collected by PSNERP focuses on key physical processes, supporting the application of this principle.

> Are physical processes a restoration target?
> Does the project identify the physical processes and recognize how those processes are impaired?

Are physical processes capable of supporting the restoration project?

The natural composition and configuration of the landscape should be restored to promote ecosystem resiliency.

The physical composition and configuration of the landscape can act as a visible surrogate for the health of physical processes (Fuerstenberg et al. 2002). The Change Analysis provides information on the historic and current frequency distribution of shoreforms based on occurrence to illustrate which shoreforms are experiencing the greatest losses.

When there were minimal stressors on the landscape what types of ecosystems were present and how were they configured?
Are there key ecosystem types that are absent or significantly impaired in the landscape?
How is the reconfigured system likely to respond to anticipated future stressors?

Restoring heterogeneity on multiple scales supports a more resilient landscape.

Heterogeneity should be restored to promote diversification and complexity but should not be increased just for the sake of heterogeneity. A historic template of ecosystems in a landscape can provide a reference from which goals of heterogeneity are based. For PSNERP, the historic and current count of shoreforms in a process unit from the Change Analysis can be used to identify segments in the landscape that have reduced heterogeneity.

Will the project/site increase the heterogeneity of the landscape to resemble the historic diversity and complexity of ecosystems?
Will the degree of heterogeneity restored support the native species assemblage?

The surrounding area has significant influence on the success of restoration efforts at a site.

The health of the landscape in which a potential restoration project resides should be analyzed as a means to assess the longevity of a project. For example, the restoration of a barrier beach may not be sustained if its sediment source is heavily armored. The Change Analysis identifies large intact areas that would benefit adjoining restoration projects, impaired sites in intact areas, and sites adjacent to degraded or heavily developed upland and nearshore areas.

Will the surrounding area support the long-term success of the project?
Is there a degraded, highly developed, or intensely used area adjacent to the project that may inhibit the long-term success?
Is the project/site located near an area that would promote the success of the restoration project?
Are the necessary resources for the restoration target present in the surrounding area?

Landscape connectivity should be restored to reduce fragmentation and facilitate the flow of energy, material, and biota between ecosystems.

Connectivity assesses the benefits a restoration project will bring to the surrounding landscape. A project that restores sediment transport between a sediment source and a sediment deprived shoreform would receive high priority under this principle. Segments of shoreline that can restore sediment transport in a drift cell can be identified in the Change Analysis as well as segments upland that can restore hydrology to downstream areas.

How will the project restore the ecological flow in the area?

Will the project restore geomorphic and/or hydrologic connectivity between ecosystems? Across the landscape?
Will the project restore land-sea interactions?
Will the project restore the movement of organisms between ecosystems? Across the landscape?

Larger patches generally encompass more ecosystem components than smaller patches.

To optimize the ecological benefits of a project, the size of the project and restored area should be assessed. A dike removal project that restores an area larger than its physical footprint or a project located in a convergence zone that can restore two drift cells would have high priority according to this principle. The Change Analysis data categorizes the number of shoreforms in normalized drift cells, allowing the calculation of the size of restored areas. Sites that would increase the restored area can also be determined by identifying impaired convergence zones from the Change Analysis data or the location of a dike that would potentially restore an area larger than its footprint.

What is the size of the project?
What is the size of the area that will be restored?
What is the ratio between the size of the project and the size of the restored area?
If a project or restored area is small, will it provide different or supplemental resources for the area?
Can a minimum dynamic area be identified?

Rare or vulnerable species and habitats should receive high priority to preserve a region's biodiversity.

The data identifies shoreforms that are rare based on their representation in a drift cell or disproportionately lost. Vulnerable ecosystems can be identified through the Future Risk Assessment which assesses threats caused by projected human populations and use. Shoreforms associated with rare or endangered species can be identified in the valued ecosystem component (VEC) white papers and scientific literature.

Will the project restore a rare ecosystem?
Will the project restore an ecosystem that is vulnerable to future threats?
Will the project promote the existence of a rare or vulnerable organism?

Ecological components that exert disproportionally greater influence on the integrity of an ecosystem should receive special attention.

PSNERP's VEC white papers provide information on shoreforms associated with ecologically important components of the nearshore environment.

Will the project restore an ecologically important ecosystem?
Will the project promote the existence of an ecologically important organism?

Cumulative impacts must be considered to accurately assess ecosystem degradation and restoration.

The synergistic impacts from environmental stressors are just being discovered. While there are many uncertainties, it is important that restoration plans acknowledge and address all stressors and the magnitude of their effects. However, cumulative impacts are not exclusively related to stressors. Restoration actions can also result in positive cumulative impacts. The Change Analysis data not only allows multiple stressors to be identified in process units as well as concurrent stressors, but the data can be analyzed to identify areas where one restoration action may restore multiple functions in a drift cell or where the cumulative actions of individual projects can restore the integrity of an entire shoreline.

Does the project address multiple stressors and their cumulative impacts?
Will the project restore impacts from multiple stressors?
Will a particular set of projects cumulatively restore the landscape?

Table 1. Lists general criteria derived from the strategic restoration and conservation principles and potential metrics to measure the criteria.

PRINCIPLE	STRATEGIES	CRITERIA AND METRICS
Conservation	Protect intact areas Protect sites adjacent to intact areas	The project will acquire an intact area The project will protect an intact area by providing a buffer The project will sustain the physical processes of an intact area The project will complement an intact area The project will increase the size of an intact area
Ecosystem-based	Use an ecosystem-based approach Address interactions between the restoration target and the landscape it resides Use a landscape-scale	Interactions between the restoration target and ecological levels above and below are addressed. The project address links between ecosystem elements and the processes that maintain them. The project is set in the context of the landscape
Physical Processes	Restore physical, landscape-forming processes	The project will restore the physical processes (hydrologic, geomorphic, disturbance regime)
Representation	Restore the natural composition and configuration of the landscape Restore the natural composition and configuration of the landscape	The project will restore an ecosystem that has experienced significant loss in a region The project will restore an ecosystem that is critically important to sustaining the integrity of the region

Table 1. Lists general criteria derived from the strategic restoration and conservation principles and potential metrics to measure the criteria.

PRINCIPLE	STRATEGIES	CRITERIA AND METRICS
Heterogeneity	Restore the historic diversity and complexity of the landscape	The project will restore multiple resources or habitats The project will increase overall heterogeneity of the area
Patch Context	Ensure the restoration site resides in an intact area that promotes success of the project and can maintain and support the long-term presence of the restoration target.	The surrounding area can support the restoration efforts The project is located in a relatively healthy area that is not heavily developed or degraded by human activity Resources in the surrounding area that are essential to the sustainability of the restoration target are intact and functioning The landscape-forming processes in the surrounding area are sufficient to sustain the long-term presence of the restoration target The surrounding area can support the future evolution of the restoration target
Connectivity	Restore connectivity in the landscape	The project will restore ecological flow in the area The project will restore the physical links to nearby ecosystems The project will promote the movement of organisms
Size	Restore large areas Restore small areas that contain supplemental or additional resources to the area	The project will restore a large area The project will provide different or supplemental resources to the area The project contains rare, vulnerable, or ecologically important species or resources
Rare/Vulnerable	Restore rare or vulnerable ecosystems and species	The project will restore an ecosystem that has experienced significant loss in size or quantity in the region The project will restore and ecosystem that is vulnerable to future threats

Table 1. Lists general criteria derived from the strategic restoration and conservation principles and potential metrics to measure the criteria.

PRINCIPLE	STRATEGIES	CRITERIA AND METRICS
Ecological Importance	Restore ecologically important ecosystems and species	The project will restore an ecotone The project will promote a keystone species or ecosystem engineer
Cumulative Impacts	Address the cumulative impacts from stressors and select projects that will have positive cumulative impacts	The project address all stressors and their cumulative impacts The project will restore multiple ecosystem functions, goods, and services

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