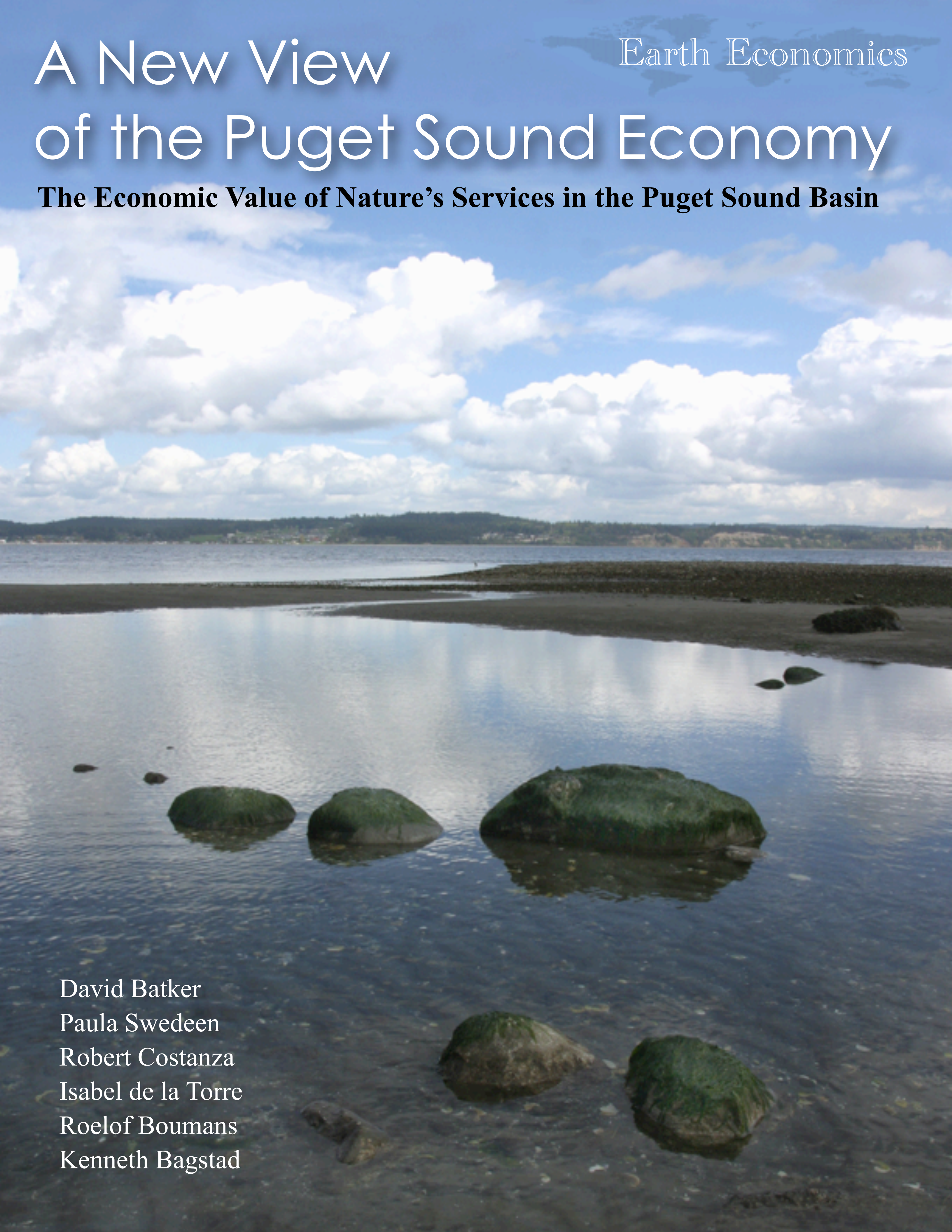
A New View of the Puget Sound Economy

Earth Economics

The Economic Value of Nature's Services in the Puget Sound Basin



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Executive Summary

Our economy is built upon the land and waters of the Puget Sound Basin. Ecosystems within the Puget Sound Basin provide between $7.4 and $61.7 billion in benefits to people every year. If the “natural capital” of the Puget Sound basin were treated as an economic asset, the asset value would be at least $243 billion and $2.1 trillion. Natural assets, such as our forests, wetlands, lakes, rivers, shorelines and Puget Sound produce economically valuable goods and services. Natural goods include fish, timber, water and agricultural products. Ecosystem services include flood protection, drinking water quality, climate stability, recreation, aesthetic value and others. The natural assets of the Puget Sound basin are tremendously valuable economic assets that are being lost and degraded.

As we lose these natural services ecosystems provide for free and in perpetuity, we suffer damages or have to pay for built capital replacements, such as levees to replace natural flood protection. Unlike natural capital, which is self-maintaining, built capital requires maintenance and depreciates.

In the last three years, Pierce County, King County and Lewis County have all received record flooding, demolishing parts of the Mt. Rainier National Park, flooding homes, farms and businesses, closing I-5 and damaging the regional economy. These floods have exacted great economic costs and are tied to the loss of natural flood protection in our watersheds and to climate change. This is not an isolated case. The Puget Sound Basin is seeing higher costs due to a loss of natural capital including damage to human health due to air, water and soil pollution, loss of water quality, more endangered species, rising costs for storm water systems, climate change impacts, and the loss of aesthetic and recreation value, all of which degrade our economy and our quality of life. Our rainwater once flowed into Puget Sound through natural systems recharging our groundwater. Impermeable surfaces and other structures now prevent water from recharging the aquifer. We have chosen to replace natural systems with storm water systems with vast long-term costs replacing what natural systems once did for free. This is an expensive way to handle water but this is how we do things at present. Replacing natural capital with built capital requires raising taxes, grand construction projects, ongoing maintenance budgets and bureaucracies. These solutions often provide fewer and far less reliable benefits than the natural systems they replace. Investing in the restoration of natural systems often provides more benefits, more reliably, over a longer period and at far less cost.

This is the most comprehensive valuation of Puget Sound basin ecosystem services to date. Yet, it is a partial value, giving a mere glimpse of the value of ecosystem services provide to people and our economy. Since this study did not value some ecosystem services, the high and low estimates are underestimates of the true values of the Puget Sound Basin natural capital. Yet a partial value is better than no value. If the value of natural capital is not considered in public and private investment decisions, we may lose more value than we gain with those investments. For example, investing in another asphalt parking lot may cause more damage in water contamination, habitat loss, storm water taxes and construction, flood damage and downstream levee construction costs than it provides in benefits for parking.

What is at stake is nothing less than our economic prosperity and quality of life. Our quality of life is excellent by any standard. Yet, while the Puget Sound Basin boasts more houses, cars, roads, buildings and other elements of “built capital” every year, most of our natural systems are deteriorating from the

foothill forests to the waters of Puget Sound. These natural systems are valuable and vital economic assets. True economics provides a better view of our full suite of economic assets including the economic benefits of natural systems which provide for our common wealth including the air we breathe, the water we drink, hospitable climate regulation, aesthetic beauty, and protection from flood and storm.

Part 1 of this study discusses the Puget Sound economy based on an understanding of the economic value of natural capital. Part 2 discusses the value of some, but not all, of the Puget Sound Basin's ecosystem services.

The study utilized current geographic information system data for mid succession forests, late to old growth forests, riparian forests, riparian shrub, freshwater wetlands, grasslands, agricultural lands, pasture, rivers and lakes, urban green-space, beach, estuary, salt marsh, eel grass beds, and marine waters. Peer reviewed primary valuation journal articles were used to peg the low and high values per acre for some ecosystem services in each of the vegetation types. Ecosystem services valued include gas and climate regulation, disturbance regulation, water flow regulation, water quality, water supply, habitat, pollination, soil and erosion control, soil formation, biological control, nutrient cycling, and aesthetic and recreational value.

While this study stands as the most comprehensive valuation to date, it is also dramatically incomplete. Of the 23 identified categories of ecosystem services, only 12 could be valued and of these 12, none were fully valued across all ecosystem types. For example, only five of 12 ecosystem services were valued for forests. This reflects the dearth of primary ecosystem service valuation studies. Valuing nature's contribution to the economy is a relatively new research area. A better understanding of the natural capital value of Puget Sound requires more primary ecosystem service valuation studies. Overall, there are few ecosystem service valuation studies from the Puget Sound Basin. Gaps exist for all ecosystem categories; there are no studies of the value of snow pack in the Puget Sound Basin, no studies for many near shore and marine ecosystem services.

Natural capital is fundamentally different from built capital. Natural capital, when it is healthy, appreciates and produces benefits for free and in perpetuity. Tacoma's water supply is filtered by forests, for free, saving taxpayers approximately $150 million in construction costs for water filtration plant and operating and maintenance costs. If kept healthy, these same forests will filter water for our great, great grandchildren. Built capital is important but it depreciates, falls apart, and requires maintenance. Like all built capital, a filtration plant requires constant maintenance and periodic reconstruction, forests don't.

One of the most important concepts to understand is that healthy natural systems provide highly valuable and often irreplaceable economic benefits for free or at a minimal restoration cost. Natural systems provide a foundation of services upon which every economy depends. The ozone layer protects humanity from ultraviolet light without charge. Plants produce oxygen. A healthy Puget Sound provides a host of economically valuable and vital benefits for people.

This pioneering report yields preliminary numbers, yet provides unmistakable conclusions:

1. Our quality of life and our economy are dependent upon "natural capital."

2. Puget Sound Basin ecosystems provide economically valuable services, including flood protection, water supply and filtration, food, habitat, waste treatment, climate regulation, recreation and other benefits. A partial valuation of these services shows a range of economic benefits between $7.4 billion to $61.7 billion/year.
3. Vegetation types examined here that provide ecosystem services include forests, riparian areas, wetlands, streams, rivers, lakes, farm land, urban forests, wetlands, beaches, eelgrass beds, and open water that is estuarine and marine.
4. The flow of annual benefits from these lands provides a vast amount of value to people across time. The present value of the benefits from these 12 ecosystem goods and services provided by Puget Sound is at least $243 billion to $2.1 trillion. This can be considered as analogous to a capital asset value.
5. There are tremendous gaps in data. Many ecosystem services easily identifiable as economically valuable have no values because no primary valuation study has been completed.
6. This analysis is static but more powerful tools for understanding the value of the natural capital in the Puget Sound Basin are being developed. These include systems and Bayesian models.
7. Large scale investments and better land use, to protect and restore the ecological capital and processes of the Puget Sound Basin are clearly justified to maintain and expand the vast value of Puget Sound natural assets.

Introduction

The Puget Sound Basin houses 4.3 million people and one of the most vibrant regional economies in the world. Today, we have a high quality of life. What makes it so? One of the most essential assets to both economic development and quality of life is "natural capital," the climate, ecosystems, nutrient cycles, water, geology, and topography that provide an abundance of goods and services for all of us. All the major cities of this region are located at river deltas and on the shores of Puget Sound. Most of the smaller upland cities and towns were founded to deliver timber, coal, food or other resources to the major cities on Puget Sound. Our economy has been successful because it was built with the spectacular natural capital of the Puget Sound Basin. That economies and natural systems are closely knit together is not an accident, it is a necessity. The natural capital of the Puget Sound Basin is an absolutely essential complement to the built economy and people's quality of life.

Every economy has a habitat. The Puget Sound land and seascapes house every city, private firm, and citizen living within the Puget Sound Basin. Yet, the economic contribution of natural assets has often been overlooked, uncounted, unvalued. What is not valued is often lost. While ecosystems like the Puget Sound Basin are priceless, Puget Sound also does work. Just as a person's life is priceless, and that person gets paid for work performed, Puget Sound ecosystems provide valuable economic goods and services. This Basin provides clean drinking water, recreation, fish, flood protection, storm buffering, and erosion control; if lost, these are valuable economic goods and services which have a price tag. The economic benefits that Puget Sound natural capital provides are valuable, and some of them can be valued.

Objectives of the Study

This study has two primary objectives: first to provide general information on ecosystem services and their connection to the economy; second, to estimate the partial dollar value of 12 ecosystem services in the Puget Sound Basin. This provides the grounding for a rough "present value" calculation and a dollar value that is analogous to the value of a traditional economic asset. Just as a building with rented offices provides a flow of income to the owner from which an asset value for the building can be derived, everyone living the Puget Sound basin receives a flow of benefits from the natural assets of the Puget Sound Basin. These estimates show that nature provides vast economic value to people and has a vital role in the health of our regional economy. This is not an end-all be-all valuation. It is a rough cut, first step in a long journey toward understanding the value of natural capital to our economy and well-being. It highlights the necessity for further study and additional primary valuation analyses.

While the estimates offered here come from the best available and current literature, they are not intended to be used for site-specific decisions, but to give the general public and decision makers an understanding of the magnitude of value that the Puget Sound Basin natural systems provide and what is at stake if this capital is lost. The study also provides background in ecological economics to help the readers understand the increasing importance of science combined with economic analysis to human well-being, sustainability, and economic progress.

Organization of the Report

This report is organized as follows. Part I provides a "new view" of the economy with a discussion of ecosystem goods and services, a methodology for estimating their value and some basic ecological economic concepts. Part II provides a valuation of 12 ecosystem services within the Puget Sound Basin and a calculation of a present value, a figure analogous to an asset value. We also discuss the flaws in this methodology, the research needed to improve our understanding of the economic role of natural capital and healthy ecosystems, and the implications of these results for the Puget Sound restoration efforts.

Why Value Ecosystem Services?

Ecosystem services often get an implicit value of zero because they are oftentimes not taken into account in decision making. However, the economic value of the goods and services provided by intact ecosystems is far greater than zero. Decisions on where and how to develop, on how much pollution is tolerable, how to handle flood waters, procure drinking water, manage land and waters, build infrastructure, and how much to invest in protecting and restoring the environment require information on the value that ecosystems provide. Beyond a certain point of degradation, ecosystems move from the realm of marginal cost and benefit considerations to highly significant social and political decisions with potentially irreversible and devastating consequences (Funtowicz and Ravets, 1994).

Be Mindful of the Gaps

Many ecosystem services have yet to be valued. This must be kept in mind when considering the results of this study. Some of the most crucial ecosystem services to human well-being, such as nutrient cycling (the natural processing of nitrogen, phosphorus and other nutrients) and disease regulation (the natural control of disease pathogens), have few or no valuation studies. Taxol, a drug for treating breast cancer, was discovered from the bark of the yew tree, yet there is no inclusion of medicinal value in this study. These and other important natural services are not easy to quantify in monetary terms so they may consistently be underrepresented in economic valuation studies. For this reason (and others discussed in detail below), the results of this study should not be used to rank the importance of different ecosystem types. Such ranking needs to remain grounded in the biological and ecological sciences. Even then ranking should be done cautiously given how much interaction there is among ecosystems and given the large amount of uncertainty around complex systems behavior (Carpenter, 2001; Limburg et al., 2002).

Figure 1. The Puget Sound Basin

Losing Natural Capital

Decisions that degrade natural systems often result in real damages that must be paid for sooner or later. Loss of flood control capacities of rivers, for instance, must be replaced by costly engineered structures or flood damage suffered. Expensive to build and maintain, these structures sometimes fail. Replacement of forests and wetlands with pavement increases flood frequency and intensity because the natural capacity of the land to absorb flood waters is lost. Society pays for these costs through increased damages to property and infrastructure, and sometimes through lost lives and livelihoods. Replacing natural services with built infrastructure requires new tax districts and higher taxes to fund the construction and maintenance of levees, storm water systems and treatment facilities. Far more economically efficient and least cost is funding restoration of ecosystems to retain the economic benefits they provide. Assigning values to some ecosystem services where appropriate helps makes the benefits and costs of decisions more explicit. While the Puget Sound Basin faces a long litany of declining natural capital, this report considers only some of the benefits that the marine and terrestrial ecosystems of Puget Sound provide.

Recent reports on the status of the Puget Sound environment such as The Puget Sound Action Team's 2007 *State of the Sound* report and the Puget Sound Assessment and Monitoring Program's *Puget Sound Update,* and a series of white papers produced by the Puget Sound Nearshore Partnership provide comprehensive reviews of many of the environmental challenges we face in the region, especially with respect to the nearshore and marine environments. These reports list some of the major threats facing the Puget Sound's biological integrity, such as:

- Habitat loss:
    - 82 percent of tidal wetlands have been lost since the advent of European settlement
    - Over one-third of the 2,500 mile shoreline has been armored causing significant loss of beach habitat for forage fish and seabirds
    - Evidence of decline of eel grass beds
    - Nearly all old growth forest has been lost from the lowland portions the Puget Sound Basin
    - Over 70 percent of old growth forest from medium and higher elevation lands has been lost
    - Floodplains and riparian areas have been nearly completely lost in urban areas and severely impacted in low-lying suburban and agricultural landscapes
    - 121,600 acres of forest have been lost between 1991- 2001 to real estate development and other uses
    - Over 160,000 acres of farmland have been lost to development since 1982

- Degraded Water Quality
    - Overall negative trends as of 2007 in marine water monitoring stations with all 39 monitoring sites showing some degradation and more sites moving into high or very high concern categories
    - 1,474 listings in 2004 of impaired waters in marine and fresh water sites mostly from toxic contamination, low dissolved oxygen, fecal coliform, and high temperatures
    - 179,000 acres of sediments in the Puget Sound are moderately contaminated with toxic substances and out of 584,000 acres studied, 5,700 acres are highly contaminated
    - Increased number, size, and duration of low oxygen (hypoxia) events in Hood Canal and other portions of the Puget Sound over the past 10 years. Leaking septic systems, run-off

from farms, and improper disposal of fish waste have exacerbated the natural causes that produce low oxygen conditions in the southern Puget Sound Basin. Hypoxic conditions are lethal to many marine organisms, especially those that cannot move to higher oxygen waters.
    - The amount of impervious surface increased by over 10 percent in the Puget Sound Basin in 1991-2001 with some areas seeing an increase of over 15 percent. This increase leads to problems with high levels of storm water run-off and increased flows of pollution into Puget Sound.

- Species decline
    - Loss of habitat and degraded water quality affects many species with whom we share the Puget Sound environment
    - 17 species are listed as federally threatened or endangered
    - Species that people depend on or like as food such as Chinook salmon, several types of groundfish, and the pinto abalone have declined to the point where harvesting is extremely limited or prohibited
    - Resident orca whales, which sit at the top of the food chain, have depressed populations and have accumulated significant levels of toxins in their tissues. The facts that their major food source, the Chinook salmon, is also a threatened population in the Puget Sound and that toxins have bio-accumulated in their bodies do not bode well for the health of the entire ecosystem.

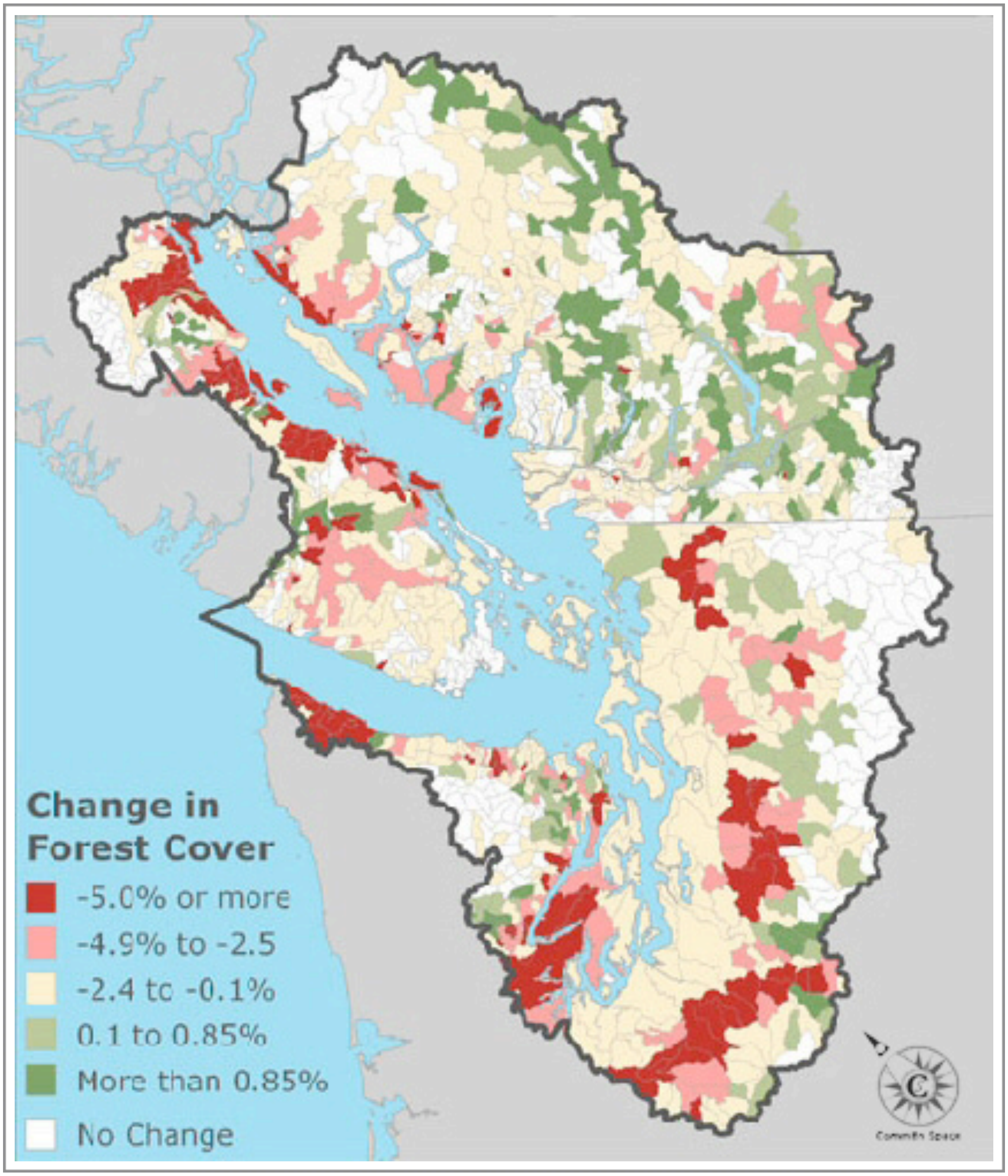

Figure 2. Change in Forest Cover in the Puget Sound (1995-2000) and Georgia Basin (1992-1999).

U.S. Environment Protection Agency, 2006

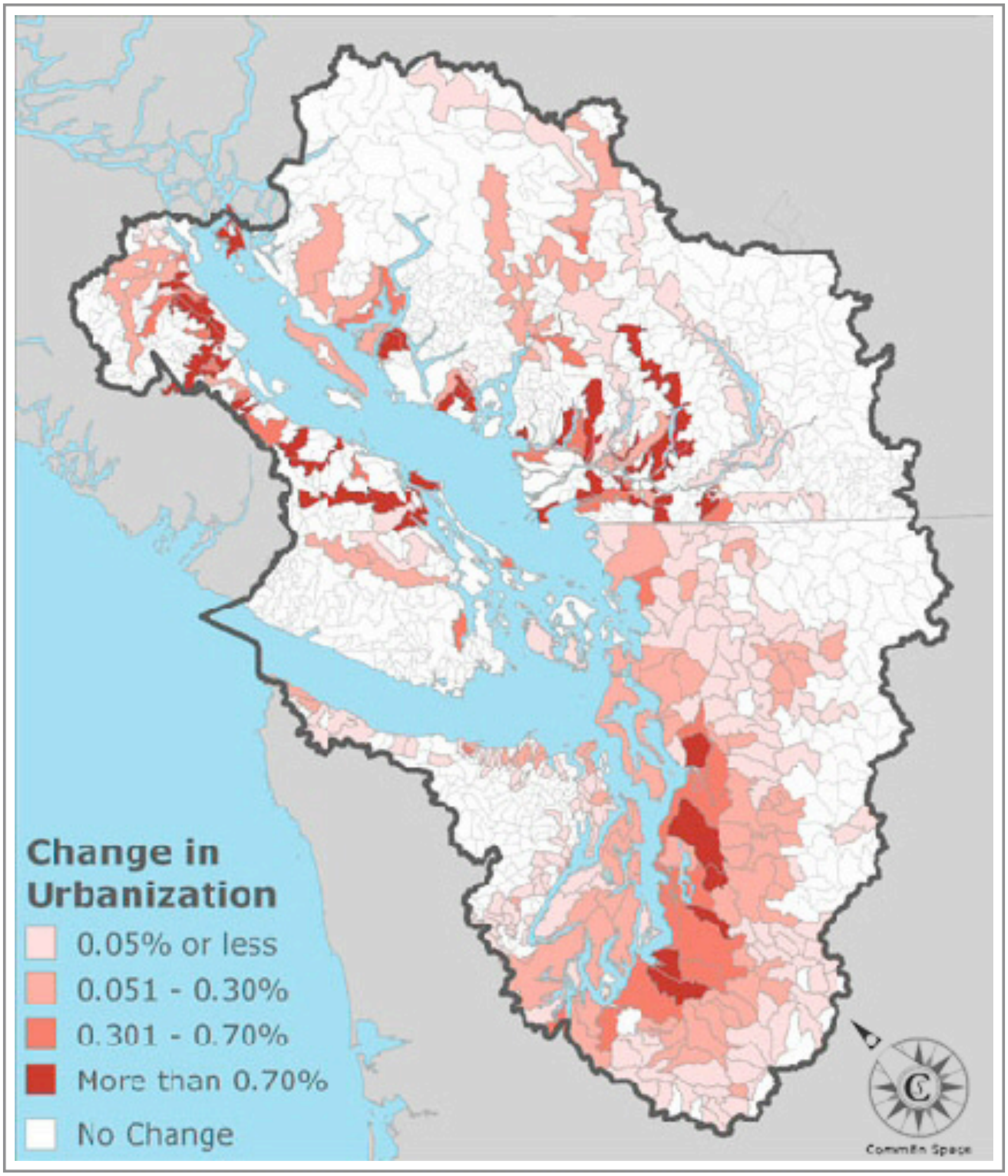

Figure 3. Change in Urbanization in the Puget Sound (1995-2000) and Georgia Basin (1992-1999).

U.S. Environment Protection Agency, 2006

A New View of Puget Sound Economy

A century ago, the expansive wilderness of the Puget Sound Basin was considered virtually limitless. Wetlands were seen as wastelands and valuable natural goods such as timber, and fish were considered to be unlimited. Economic development at that time meant converting the otherwise “wasted” natural resources into useful goods. Because natural systems produce abundant public goods and benefits such as breathable air, water, and fish without the requirement of human labor, charge, or restriction (everyone can breathe as much air as they want for free), natural systems were viewed as void of economic value. On the other hand, human-built capital was scarce, and thus valuable.

We need housing, food, transportation and energy and income. We need built capital for a high quality of life. Providing built capital has been the focus of economic development. Importantly, all built capital is derived from natural capital. Every car, building, shirt and cell phone is made from natural resources. All energy is derived from nature. Built capital must be understood in the context of natural capital.

Markets now produce previously scarce items, such as clothes, and asphalt in far greater abundance, while nature’s goods and services are increasingly more scarce and valuable. Limits to oil, land, water, and forests are constraining production more than a lack of factories. A century ago, more built capital was needed to increase production. For example, more nets and fishing vessels were needed to increase fish production while today, seasonal, gear and other limits show an overabundance of built fishing capacity. Today, to increase fish production requires more fish and the natural habitat (natural capital) which produces them, not more built capital. It is critical that infrastructure and built capital be produced within a context of sustainability. Otherwise we risk losing both sustainability of resources and ecosystems and economic development.

In the past, the environment and natural resources have often been considered a small part of a larger economy, and relatively small contributor to it as Figure 4 illustrates. However, satellite photos reveal that the Puget Sound economy is physically set within the landscape. In fact, the economy is housed within a set of ecosystems and natural features. The scientifically correct relationship between the economy and environment is shown in Figure 5. The economy is a subset of the larger environment. The economy is dependent on basic foundational ecosystem functions and landscape features. The economy cannot function without an ozone layer, oxygen, land, water, energy, climate stability, flood control (most rainwater is handled by natural systems). Economic success requires sustainability in the natural systems which house and support the economy.

In the last century, we have shifted from a seemingly empty world of unlimited and stable resources and natural systems to a full world scenario where natural resource limits are more pressing, and global systems like climate and ozone protection can be disrupted. Today, natural capital is scarce and of greater value while built capital is more abundant and relatively less valuable.

Incorrect 20th Century View

Correct 21st Century View

Economies must adjust as the economy reaches physical boundaries. When it became apparent that certain chemicals were destroying the earth's protective ozone layer, it was in the interest of all economies to place a global ban on those chemicals. This was accomplished through the Montreal Protocol.[1] Defining the best boundary between the economy and ecosystems is an issue of ***scale***. Ecological economics, arguably one of the fastest growing areas in the field of economics, specifically examines the relationship between ecosystems, the economy, and human well-being. Securing a sustainable and prosperous economy in a full-world scenario requires meeting four important economic goals.

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[1] The Montreal Protocol on Substances That Deplete the Ozone Layer is an international treaty to control and phase out the production and consumption of ozone depleting chemicals, primarily chlorofluorocarbons (CFCs). The Montreal Protocol is often considered one of the most successful international environmental agreements.

1. Sustainable Scale: appreciating the physical limits of natural systems which contain and sustain the economy and figuring out the proper relationship of economies to those limits.
2. Fair Distribution: how benefits, including the benefits from ecosystem services, are distributed among people. The benefit of flood protection, for example, is provided within the boundaries of a watershed (provisioning area); the greatest beneficiaries are those living in the watershed's lower deltaic areas (benefit area). On the other hand, oxygen production is a globally produced and globally distributed economic benefit.
3. Efficient Allocation: how and where resources are moved or invested to produce different suites of things. Often markets determine allocation and distribution and involve a complex system of ownerships, markets, productive organizations, and governments. Ecosystems also allocate resources, water, air and soil to produce goods and services. Factories are more efficient at producing toys. Ecosystems are more efficient at producing oxygen and biodiversity. Flood protection is often most efficiently produced with a combination of natural (forests) and built (levees) capital.
4. Good governance: institutions, private or public, markets or non-market have a great deal of control over the distribution and allocation of resources. Markets need to include the full cost of activities; otherwise allocation and distribution will be distorted toward damaging activities. Government institutions need to be at the scale of the issue or problem they are intended to address and provided with sufficient powers and resources to achieve their mission. The recently created Puget Sound Partnership is an institution at the correct scale for protecting and restoring Puget Sound.

The economy operates within a sustainable scale in the landscape regarding required ecosystem services, such as flood protection and water requirements. The economy also requires decisions about fairness and property rights, fairness between areas provisioning ecosystem services and recipients, for example. This deals with defining our common wealth and the interaction between common wealth benefits such as flood protection, and actions on private property that affect common wealth assets such as the air and water. Efficiency looks at allocation systems, markets, funding mechanisms, private and public owners, utilities, tax districts, and other areas, this is also not discussed in this report. In addition to considering the size of the economy in relation to its supporting ecosystems, ecological economists offer another helpful tool: the four capitals that are required to attain economic progress and a high quality of life; these include:

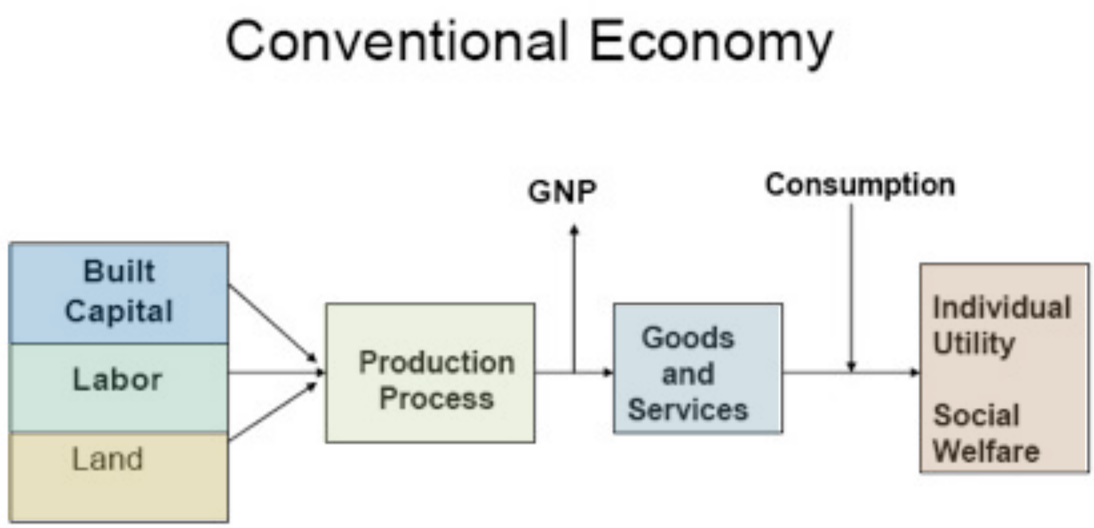
1. Natural Capital: refers to the earth's stock of organic and inorganic materials and energies, both renewable and nonrenewable, as well as the planetary inventory of living biological systems (ecosystems) that when taken as one whole system – provides the total biophysical context for the human economy. Nature provides the inputs of natural resources, energy, and ecosystem function to human economic processes of production. Nature by itself produces many things that are useful and necessary to human well-being.
2. Human Capital: includes acquired knowledge through education, self-esteem, and interpersonal skills such as communication, listening, and cooperation as well as creating individual motivation to be productive and socially responsible. It is well recognized that education and training are essential to economic growth, innovation and a high quality of life.
3. Social Capital: is the inventory of organizations, institutions, laws, informal social networks, and relationships of trust that make up or provide for the productive organization of the

economy. Without a functioning society in which people respect each other and have some concern for the well-being of others, most economic activity would be impossible.

4. Built Capital: is the productive infrastructure of technologies, machines, tools, and transport that humans design, build, and use for productive purposes. Coupled with our learned skills and capabilities, our built techno-infrastructure is what directly allows raw materials to be turned into intermediate products and eventually finished products.

This also provides a new view of the economy. With roots in the industrial revolution, economics has focused greater research on the production of manufactured capital. This has yielded a highly productive market system for manufactured capital. Economics has provided a poor measurement of human, social, and natural capital productivity. Capital and labor have been the primary “factors of production.” Occasionally land and resources are also included in economic analysis. Figure 6 provides a sketch of this perspective.

Figure 6. Model of the Economy that Excludes Natural Capital (adapted from Costanza et al. 1997a).



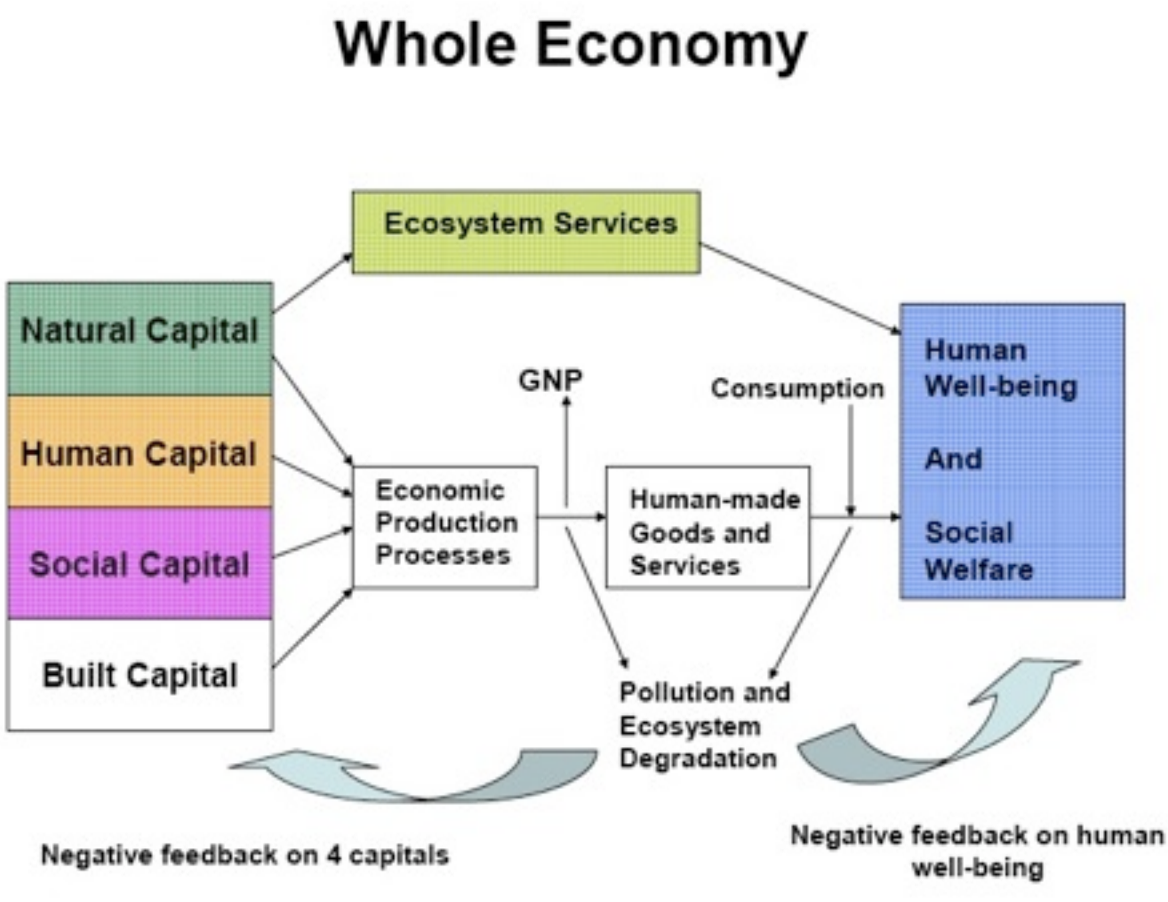
A broader view of what goes into making a fully functional economy has emerged as natural capital has become scarcer and research has demonstrated that people’s well-being is more closely tied to health, social systems, and ecological assets (Easterlin, R. A. 1995).

Natural capital has been characterized as something that human-built alternatives can replace; however, in many cases, built capital cannot replace a natural capital like biodiversity. In addition, all built capital requires natural capital inputs of material and energy. Natural capital and built capital are most often productively used as complements rather than substitutes (Daly and Farley 2004). Fishing boats, which are human built capital, are useless without fish, natural capital. Built and natural capital, are complements, both required to put fish on the table, or pour water from the spigot.

The four capitals weave together to build a robust economy. The presence of a balance of all four capitals promotes people's well-being. Recent analysis demonstrates a high level of correlation at the national level between human, built, and natural capital; especially the presence of adequate natural capital and subjective well-being (Vemuri and Costanza, 2006).

Human well-being requires all four capitals. The purpose of an economy is to support human well-being (Daly and Cobb, 1994). Actions which degrade human, social, or natural capital degrade the economy and the factors that support human well-being. The relationship between loss of natural capital and the services it provides result in a decline in human well-being; this can be measured through formal economic processes (like loss of jobs, higher prices for consumer goods). This report focuses on the contribution of natural capital to the Puget Sound region's economy; human and social capitals are beyond the scope of this report. Figure 7 illustrates the fuller vision of an economy that takes all four capitals into account.

Figure 7. Ecological Economic Model of the Economy (Adapted from Costanza et al. 1997a).



Understanding Natural Capital

Natural capital comprises of geology, nutrient and water flows, native plants and animals, and the network of natural processes that yield a continual return of valuable benefits (Daly and Farley, 2004). It contributes to our economy and quality of life in many ways that are not currently included in market transactions or policy considerations. Natural capital contributes to the provision of water, natural water filtration, energy production, flood control, recreation, natural storm water management, biodiversity, discovery of new medicines, and education. Ecosystems are defined as all the interacting living and nonliving elements of an area of land or water. Ecosystem functions refer to the processes of transformation of matter and energy in ecosystems. Ecosystem goods and services are the benefits that humans directly and indirectly derive from naturally functioning ecological systems (Costanza et al., 1997; Daily 1997, De Groot et al., 2002; Wilson, Troy and Costanza, 2004). These goods and services flow from intact natural capital. The determination of an ecosystem good or service requires that it benefits people.

The Economics of Natural Capital

Healthy ecosystems are self-maintaining. They have the potential to appreciate in value over time and to provide an ongoing output of valuable goods and services in perpetuity. In contrast, built structures and other man-made capital depreciate in value over time and require capital investment and maintenance.

The provision and filtration of water is a good example. The city of New York requires a daily supply of more than one billion gallons of water. Facing degraded drinking water quality, New York City weighed the options of building a water filtration plant that would cost over $6 billion and $300 million/year to operate, or investing $1.5 billion to restore the health of the watershed and allow natural processes to filter the water and meet drinking water standards. The City decided to invest in the restoring the watershed because it has a far higher rate of return, is less costly, and more likely to meet water quality standards (Worldwatch Institute, 2005).

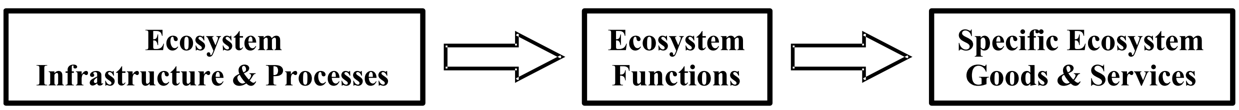
The Puget Sound region has better examples. The city of Tacoma has maintained forested watersheds that supply water at above drinking water standards. With forests filtering drinking water, the city of Tacoma have avoided capital construction costs for water filtration plants that would have cost $150 million. In addition, filtration plants would require maintenance and replacement. The forest is essentially a self-maintaining water supply and filtration system. If we do not consider the economic value that these ecosystems provide, we may lose them at great cost.

Ecosystems and Value Production

Ecosystems consist of structural components (trees, wetland plants, soil, hill slopes, etc.) and dynamic processes (water flows, nutrient cycling, animal life cycles, etc.) that create functions (water catchment, soil accumulation, habitat creation, reduced fetch, buffers to hurricane storm surges, etc.) that generate ecological goods (fish, timber, water, oxygen) and services (storm and flood protection, water filtration, recreation, aesthetic value, etc.).

Ecosystem infrastructure has particular physical components such as the eel grass beds, salt marsh, herbaceous and forested wetlands, coniferous and deciduous forests. The infrastructure itself is dynamic, as biotic structures migrate and abiotic components flow through the Puget Sound Basin, often via air or water. For example, our rivers show a great deal of dynamism grading the deposition of gravel, sand and silt, to provide just the right habitat (sorted pea gravel) for salmon spawning. These functions vary widely in spatial boundaries; oxygen migrates globally, salmon range into the North Pacific, while drinking water production is locally confined. Thus ecosystems may provide benefits that extend globally (carbon sequestration) or locally (drinking water production). These structures, processes, and functions combine to produce economically valuable goods and services. Figure 8 summarizes these relationships in a simplified diagram.

Figure 8. Relationship of Ecosystems to the Goods and Services Produced



Valuation of Ecosystem Goods and Services

Ecosystem service valuation assigns a dollar value to goods and services provided by a given ecosystem. This allows for proposed management policies to be considered in terms of their ability to improve ecological processes that produce the full diversity of valuable ecosystem goods and services. This study will present the low and high value estimates for some goods and services provided within the Puget Sound Basin. Goods are physical things, such as water, timber, and fish; services, being less tangible, provide benefits that are more difficult to measure, for example recreation, natural water storage, water filtration, flood protection, and aesthetic value.

Most ***goods*** are excludable. If a person owns or uses a particular good, that person can exclude others from owning or using the same, i.e., if one person eats an apple, another person cannot eat that same apple. Excludable goods can be traded and valued in markets. The production of goods can be measured by the physical quantity produced by an ecosystem over time. The stream of goods provided by natural capital over time is called a ***flow*** of benefits; examples of this are the volume of water production per second, the board feet of timber production in a 40-year rotation, or the weight of fish harvested each year. The current production of goods can be easily valued by multiplying the quantity produced by the current market price. This production creates a flow of ecosystem goods over time.

Ecological ***services*** are defined as "the conditions and processes through which natural ecosystems and the species that make them up sustain and fulfill human life." (Daily et al., 1997). Ecosystems provide a variety of services that individuals and communities use and rely upon, not only for their quality of life, but also for economic production (Daily, 1997; Costanza et al., 1997). Ecosystem services are measurable benefits that people receive from ecosystems.

"S***ervice flux***" refers to the stream of services that an ecosystem provides. This service flux cannot be measured as the quantity of a physical product; it is more difficult to measure and value, for example. storm buffering of wetlands, water filtration, or recreational value. Ecosystem services are in many cases non-excludable services. Wetlands provide flood buffering and water cleansing to anyone downstream, and aesthetic value to anyone who looks at them. As a result of this non-excludability, most ecosystem services cannot be traded or sold in markets. Table 1 shows a partial list of ecosystem services.

Table 1. Examples of Ecosystem Services

Purification of the air and water
Mitigation of floods and droughts
Recreation
Detoxification and decomposition of wastes
Generation and renewal of soil and soil fertility
Pollination of crops and natural vegetation
Control of the vast majority of potential agricultural pests
Dispersal of seeds and translocation of nutrients
Maintenance of biodiversity
Protection from the sun's harmful ultraviolet rays
Partial stabilization of climate
Moderation of temperature extremes and the force of wind and waves
Support of diverse human cultures
Provision of aesthetic beauty

Daily et. al., 1997

Structure and Value Production

The quality, quantity, reliability, and combination of goods and services provided by the ecosystems within the Puget Sound Basin depend on the structure and health of ecosystems. Structure refers to a specific arrangement of ecosystem components. The steel, glass, plastic, and gasoline that comprise a car must retain a very particular structure to provide the service of transportation. A pile of the same constituent materials without a car's structure cannot provide transportation. Salmon require certain processes, structures, and conditions: habitat. The natural provision and filtration of drinking water requires a forested watershed. Ecological service production is more dependent on structure than the flows of goods. A single species timber plantation may yield a flow of goods (timber) but it cannot provide the same service fluxes (biodiversity, recreation, and flood protection) as an intact natural forest.

Integrated Ecosystems and Multiple Benefits

A heart or lungs cannot function outside the body. Neither can the human body function without a heart and lungs. With all the organs functioning, a body can perform many tasks. Good bodily health requires organs to work as parts of a coordinated system. The same is true for ecosystems. Interactions between the components make the whole greater than the sum of its individual parts. Each of the separate physical and biological components of the Puget Sound Basin would not be capable of generating the same goods and services provided by the processes and functions of a whole intact watershed system (EPA, 2004). Natural channel migration in rivers creates and destroys wetlands, provides gravel sources for salmon, and moderates salinity gradients. Intact ecosystems provide a full basket of valuable, diverse goods and services. The Puget Sound basin provides fish, land for habitation and industry, storm protection, clean water, recreation, and flood control. Built structures, such as levees or fish hatcheries may partially replace one function, but not the full basket of goods and services. They can also harm other functions and services. Ecosystems are engines of economic productivity and hold significant complexity. Individual services influence and interact with each other, often in nonlinear ways. If stressed beyond critical thresholds, collapse may ensue.

Resilience

Resilience implies the potential of a system to, after disturbance, return to a previous state. A system is assumed to be fragile when resilience is low. Fragile systems tend to be replaced after disturbance; for example, wetlands that are converted to open water produce reduced amounts of ecosystem services and provide less economic value (Gunderson and Holling, 2002). While signs may be present when an ecosystem is on the verge of collapse, there is, with the exception of a few well-studied systems (Carpenter, 2001), little science available to show the minimum threshold of ecosystem infrastructure necessary to stop the breakdown of services. Ecosystems have been shown to be quite resilient; in some cases ecosystem health improves when restoration projects are initiated. Experience in rebuilding wetlands, for example, have secured greater resiliency (Tibbetts, 2006).

Value Production "In Perpetuity"

The Puget Sound Basin has contributed to human economies and a high quality of life for thousands of years. Healthy intact ecosystems are self-organizing (require no maintenance) and do not depreciate. They can provide valuable ecological goods and services on an ongoing basis or "in perpetuity." A forest can provide water control, flood protection, aesthetic and recreational values, slope stability, biodiversity, water filtration, and other services without maintenance costs. This differs from human-produced goods and services (cars, houses, energy, telecommunications, etc.) that require maintenance expenditures, dissipate, may depreciate, and usually end up discarded, requiring further energy inputs for disposal or recycling.

For instance, a sea wall built to protect areas inland from storm waves and erosion costs money to build. The community or individual who owns it must pay periodic maintenance costs to ensure that the wall keeps functioning. When the wall wears out in 30 -40 years, the whole thing must be torn down and replaced. In addition, the wall affects the dynamics of the coastline, making neighboring landowners more vulnerable to the impact of currents and waves. In contrast, relying on ecological features for storm protection, including building in areas that are naturally protected from storms, is less costly and less risky. Keeping coastal wetlands, rock reefs, and kelp beds all intact, and not building right on top of bluffs, uses natural capital to enhance a community's long-term safety with no physical capital maintenance costs.

The benefits of natural capital in Puget Sound can be quickly and permanently lost through mismanagement. The loss of an ecosystem's natural flood or storm prevention functions can exact large, long-term, and accelerating costs on private individuals, businesses, communities, and governments. For example they may suffer increased storm and flood damage, pay for expensive and often less effective engineering solutions, spend on increased repair or replacement costs, higher insurance premiums (or loss of access to insurance) as these natural and economically valuable services are lost. When ecological services are restored, the reverse dynamic can occur.

Greatly altered systems, such as urbanized areas of Puget Sound, require a combination of built structures, such as storm water treatment or levee setbacks to restore natural processes. Maximizing benefits requires both built and natural systems.

Understanding the value of natural capital is important for all decision makers from individual residents to corporations, local governments and the federal government. Everyone and each institution holds assets, earns income or participates in the long-term economic planning for the region. Everyone would be better informed for making good decisions knowing the importance and value of Puget Sound natural systems.

Ecosystem Services as Common Wealth

Some ecological goods, such as salmon and Dungeness crab, can be captured and distributed privately through the market. Many ecosystem services, by their nature, cannot be privatized and are thus "non-market" goods or services; examples are clean water, breathable air, and flood control services. It is now understood that public ecosystem services are highly important and contribute to our common well-being. These are "common wealth" assets. Institutions of governance are required to protect and manage common resources and to ensure the equitable access to benefits for this and the future generations. As these once abundant common wealth assets have become increasingly scarce, the proper governance and protection of our common wealth has become far more important.

It is very important for wise governance policies to be adopted, particularly in a region such as the Puget Sound Basin, to clearly understand the relationship between natural ecosystem services and economic well being:

1. The ecological common wealth of the Puget Sound Basin provides vast and essential benefits to people.
2. Ultimately, all private wealth depends upon the common wealth of nature
3. If fundamental biophysical systems decline the economy will eventually decline and human well-being will suffer.

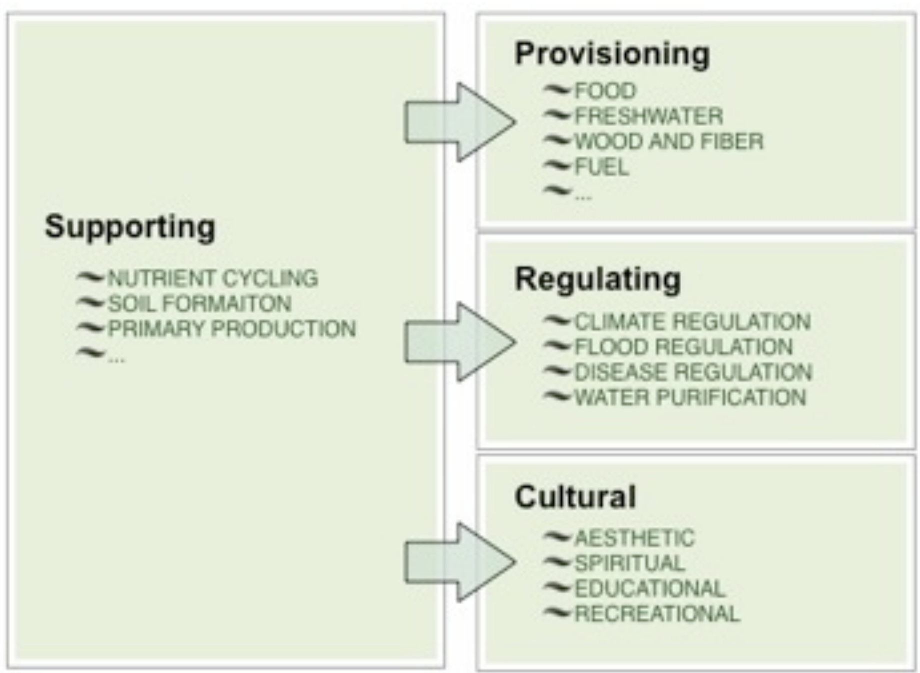
A few examples of vital natural goods and services and the capital assets that provide them include:

1. Protection from deadly ultraviolet light by the ozone layer.
2. Provision of oxygen and primary food production from photosynthesis.
3. Maintenance of climate stability within a habitable range by the atmosphere and its processes.
4. Retention of a non-toxic environment by biological agents (bacteria).
5. Production of food from a combination of natural and human systems.

Ecosystem Services of the Puget Sound Basin

Ecosystem services fall into four broad categories (Figure 9), a basic scheme that was developed in the Millennium Ecosystem Assessment (UNEP, 2005). Other authors place ecosystems in 23 finer-scale categories (e.g., De Groot et al., 2002). Provisioning service is one of the four broad categories of ecosystem services that directly provides the materials for subsistence and economic activity; this includes food, building materials, fiber for clothing and other implements, medicines, and fuel. Ocean ecosystems produce fish, crustaceans, and other organisms that humans have relied on for food throughout human history. Forests, as another familiar example, provide trees for building materials and other plants used for medicinal purposes. Taxol, a cure for ovarian and breast cancer was discovered from the bark of the Pacific yew tree (*Taxus brevifolia*), a native tree of the Puget Sound basin. A regulating service is one that creates and maintains conditions favorable to human life and economic activity. Climate stability, cycling water from oceans to land, keeping disease agents in check, and breaking down waste products are all examples of regulating services. Supporting services are the basis of ecosystem function. These include primary productivity – nutrient cycling and the fixing of CO_2 by plants to produce food that forms the basis of the vast majority of all food webs on the planet. Cultural services include all the ways that people interact with nature in socially meaningful ways, such as spiritual significance, enjoying natural places for recreation, and learning about the planet through science and education.

Figure 9.



We describe 1 … e Puget Sound Basin. Table 2

Millennium Ecosystem Assessment, 2005

Table 2. **Ecosystem Services Definitions and Examples**

Ecosystem Service	Definition	Examples

Biodiversity	The number and types of species and the ecosystems they comprise. Measured at gene, population, species, ecosystem, and regional levels. Biodiversity provides resilience to ecosystems and the opportunity for the provision of most other ecosystem services.	Intact fish populations occur within more intact native species and ecosystem assemblages than those populations which are in decline. Forests that have higher biological diversity tend to be more resilient to disturbances.
Provisioning		
Food	Biomass for human consumption, provided by a web of marine organisms and a functioning marine ecosystem (see biodiversity definition above).	Crops, mushrooms, berries, game, fish, seaweed.
Materials	Biological materials used for medicines, fuel, and building.	Trees for timber, conical mollusk shells used for anti-cancer drugs, oil, lime.
Regulating Services		
Shoreline Stabilization	Keeping shorelines in a state of equilibrium with ocean waters, especially in the face of rising sea levels.	Rocky shores, seagrass beds, wetlands, and estuaries trap sediments and sand that allow land accretion which can balance or exceed subsidence or erosion.
Storm Protection	Mitigation or attenuation of the effects of wind, waves, and flood waters on coastal land and communities.	Estuaries and coastal wetlands absorb wave energy and flood waters from ocean storms, thus reducing damage to coastal property
Water Flow Regulation	Retention and storage of fresh water.	Estuaries and coastal wetlands store fresh water and keep salt water from intruding upon fresh water supplies.
Human Disease Control	Undisturbed ecosystems keep in check organisms which can cause disease in humans.	Coastal waters with proper nutrient, oxygen, and pH levels prevent algal blooms that produce toxins which are poisonous to humans via shellfish consumption from affected areas.
Waste Processing	Detoxification or absorption of natural or human-made contaminants.	Wetlands take out excess nitrogen and biologically breakdown contaminating bacteria from human waste, thus preventing release to marine waters.
Carbon Sequestration	The capture and long-term storage of carbon is part of the global carbon cycle. Oceans play a crucial role in climate stabilization.	Oceans absorb carbon both chemically and biologically. Surface absorption occurs over short time frames (1 year); deep water mixing allows long-term storage and more surface absorption; phytoplankton fix carbon through photosynthesis.
Supporting		
Nutrient Regulation and Cycling	Transfer of nutrients from one place to another; transformation of critical nutrients from unusable to usable forms.	Estuaries are zones of mixing of nutrients from fresh water and saltwater systems, making them very productive; anadramous organisms transport marine nutrients to upland habitats where they are used by terrestrial organisms (salmon and grizzly bears) and enhance primary productivity of terrestrial plants.
Habitat	Providing for the life history needs of plants and animals.	Estuaries provide nursery habitat (relatively more protected places where fish and other sea animals hatch then mature to a life stage where they can handle harsher environments)

Primary productivity	Fixing of carbon by plants; provides basis of all terrestrial and most marine food chains.	Forests fix carbon and produce oxygen. Agricultural lands provide food plants for humans and livestock. Phytoplankton plays a crucial role as the basis of marine food webs and in the global carbon cycle.
Cultural		
Spiritual	The role which ecosystems and their components play in the spiritual beliefs of people. This is especially important for indigenous cultures. These values do not lend themselves well to economic quantification.	Salmon play a key role in spiritual and cultural life of Native American tribes.
Scientific and educational	Ecosystems are the subject of much scientific study for both basic knowledge and for understanding the contribution of functioning ecosystems to human well-being.	Research institutions focused on marine habitats contribute economically and socially significant knowledge to society.
Tourism	The explicit role that intact land and seascapes play in attracting people to areas for vacationing	Visits to national forests and parks to see views of mountains, hike in forests and meadows, and to see wildlife.
Aesthetic	The role which natural beauty plays in attracting people to live, work and recreate in an area	Home values with water views or forested mountain views are higher than homes without.
Recreation	The contribution of ecosystem features like biological diversity and clean water play in attracting people to engage in recreational activities.	Clean water and marine animals attract kayakers and scuba divers.

Tables 3, 4 and 5 examine marine aquatic, terrestrial, and freshwater ecosystems, and the ecosystem services that are provided within different vegetation types, landforms and habitats. X indicates that an ecosystem service is present.

Table 3. Marine and Estuarine Ecosystem Types and the Services They Provide

	Beaches	Salt Marshes	Mud Flats	Intertidal	Kelp	Rock Reefs	Eelgrass	Inner Shelf
Biodiversity	X	X	X	X	X	X	X	X
Provisioning Services								
Food	X	X	X	X	X	X	X	X
Fiber, Fuel		X			X			X
Medicines		X			X			X
Regulating Services								
Shoreline Stabilization/Erosion Control	X	X	X			X	X	
Storm Protection	X	X		X	X	X	X	
Water Flow Regulation and Storage		X						
Human Disease Control	X	X	X	X		X	X	
Waste Processing	X	X	X				X	
Carbon Sequestration		X	X	X		X	X	X
Supporting Services								
Nutrient Cycling	X	X	X	X	X	X	X	X
Habitat	X	X	X	X	X	X	X	X
Primary Productivity		X			X		X	X
Cultural								
Spiritual	X	X		X	X	X	X	X
Scientific and educational	X	X	X	X	X	X	X	X
Tourism/Recreation	X	X	X	X	X	X		
Aesthetic	X	X		X				

Table 4. Terrestrial Ecosystem Types and the Services They Provide

	Forests	**Grasslands**	**Meadows**	**Crop-lands**	**Pastures**	**Urban Green space**
Biodiversity	X	X	X	X	X	X
Provisioning Services						
Food	X	X		X	X	
Fiber, Fuel	X	X		X	X	
Medicines	X			X		
Regulating Services						
Erosion control	X	X	X	X	X	X
Storm protection	X					
Water flow regulation and storage	X	X	X	X	X	X
Human disease control	X					
Waste processing	X	X	X			X
Carbon sequestration	X	X	X	X		X
Pollination	X			X	X	X
Supporting Services						
Nutrient cycling	X	X	X	X	X	X
Soil formation	X	X	X	X	X	X
Habitat	X	X	X	X		X
Primary Productivity	X	X	X	X	X	X
Cultural						
Spiritual	X	X	X		X	X
Scientific and educational	X	X	X	X		X
Tourism/Recreation	X	X	X	X	X	X
Aesthetic	X	X	X	X	X	X

Table 5. **Freshwater Aquatic and Associated Ecosystem Types and the Services They Provide**

	Rivers and Lakes	**Wetlands**	**Riparian Areas**	**Ice and Snow Fields**
Biodiversity	X	X	X	X
Provisioning Services				
Food	X	X	X	X
Fiber, Fuel		X		
Medicines		X		X
Regulating Services				
Shoreline Stabilization/Erosion Control	X	X		
Storm Protection	X	X	X	X
Water Flow Regulation and Storage		X		X
Human Disease Control	X	X	X	
Waste Processing	X	X		
Carbon Sequestration		X	X	
Supporting Services				
Nutrient Cycling	X	X	X	X
Habitat	X	X	X	X
Primary Productivity		X		X
Cultural				
Spiritual	X	X	X	X
Scientific and educational	X	X	X	X
Tourism/Recreation	X	X	X	X
Aesthetic	X	X	X	X

Description of Puget Sound Ecosystem Services

Biodiversity

Biological diversity is defined as the number and types of species and the ecosystems they comprise. It is measured at gene, population, species, ecosystem, and regional levels (Magurran, 1988). For all ecosystems, biodiversity is both a precondition of the flow of ecosystem services and an ecosystem service in itself (UNEP 2005, Vol. 1, Chapter 11). It is a precondition because ecosystems with their full native complement of species tend to be more resilient to change in environmental conditions or external shocks, and they tend to be more productive. Biodiversity is also an ecosystem service in itself because novel products have been derived from genetic and chemical properties of species, it provides a secure food base (multiple sources of food with different seasonal availability), and people ascribe value to it simply for its existence.

Likely one of the more diverse areas in North America, the Puget Sound Basin is home to a rich diversity of species and ecosystems. A recent assessment found that there are at least 7,013 species, including animals (both vertebrate and invertebrate), flowering plants, fungi, and marine algae in all habitat types of the Puget Sound Basin (Center for Biodiversity, 2004). Given that little is known about some invertebrates and most microorganisms, the total is likely much higher.

Western Washington forests are home to 82 species of mammals, 120 bird species, 27 amphibian species, 14 reptile species (Olson et al. 2001), and several thousand invertebrate species including fresh water mussels, insects, and arthropods (FEMAT, 1993). All seven species of salmonids found in the Puget Sound use forested streams and rivers for part of their life-cycle. Many forest species depend on or are at their highest abundance in late-successional or old growth forests (FEMAT, 1993; Carey et al.1996).

Large portions of the forest landscape in the Puget Sound Basin are managed as planted Douglas fir monocultures with short rotations (35-40 years on private lands and 60-70 years on state lands). These forests have simpler structure, perform fewer ecological functions, or perform them at lower levels, and have lower species diversity and species abundances than late-successional forests or naturally young stands with biological legacies (Ruggerio et al.1991, FEMAT 1993, Carey et al.1996, Franklin et al. 2002). The species that comprise forest ecosystems participate in numerous ecological functions, some contribute to properties that emerge in the later stages of natural forests; thus, how management influences these species will in large part determine how well-managed forests function (Marcot, 1997; Carey et al.,1999). The loss of forest complexity and associated biological diversity is then a concern in intensively managed landscapes (National Research Council, 1999).

Although a comprehensive survey of species in these habitats is lacking, marine and nearshore ecosystems are equally if not more impressive in terms of species diversity (Kruckeberg, 1991). There are 284 regularly-occurring wildlife species, including 219 birds, 58 mammals, both terrestrial and marine, 7 reptiles, and 3 amphibians (Buchanan et al., 2001), and 211 species of vertebrate fishes. Invertebrate species (crabs, clams, starfish, sea cucumbers, and tube worms, for example) in the Puget Sound number in the thousands, with all taxonomic families represented. Benthic microorganisms, which are poorly cataloged, probably number in the thousands.

A recent meta- analysis of marine data and studies examining the effects of biodiversity on ecosystem services found strong evidence that loss of biodiversity leads to fisheries collapse, lower potential for stock and system recovery, loss of system stability, and lower water quality. The relationship is one of an exponential loss of ecosystem services with declining diversity (Worm et al., 2006). In contrast, Worm et al. also found that restoration of biodiversity, including through the establishment of marine reserves protected from fishing pressures, leads to a fourfold increase in system productivity and a 21 percent decrease in variability (i.e., an increase in stability). This study provides the best evidence to date of the direct relationship between biological diversity and ecosystem services in the marine environment.

At a global scale, the loss of biodiversity in all ecosystems through over-harvest, habitat degradation and loss has been substantial in marine and coastal ecosystems, forests, grasslands, and agricultural systems, and therefore has large implications for maintenance of ecosystem services (UNEP, 2005 and 2006). Over-fishing and habitat loss have affected Puget Sound's fish stocks; urbanization and industrial development have led the loss of large portions of historical forest and wetland cover; and pollution and land loss to residential and commercial development continue to threaten the continued persistence of many species and ecosystems. There are currently 17 species listed as federally threatened or endangered that live in the Puget Sound Basin, though the Center for Biodiversity (2004) estimates that there are at least 285 species that are critically imperiled.

Provisioning Services

Provisioning services are those that provide basic materials to people (De Groot et al., 2002; UNEP, 2005). Forests grow trees that can be used for lumber and paper, berries and mushrooms for food, and other plants for medicinal purposes. Rivers provide fresh water for drinking and fish for food. The waters of the Puget Sound provide fish, shellfish, and seaweed. These are the most familiar services and also the easiest to quantify in monetary terms (Farber et al., 2006).

Food and Materials

Providing food is one of the most important functions of marine ecosystems. Globally, fish and seafood provide the primary source of protein to one billion people. Fishing and fish industries provide direct employment to some 38 million people (UNEP, 2006). It is also important to note that most of the fisheries catch comes from within coastal areas, putting a great deal of pressure on a small portion of the total marine environment. Other important materials, including petroleum, lime, wood, and medicinal products come from coastal and marine ecosystems. Salmon, steelhead, sturgeon, goeduck clams, crab, sea urchins and sea cucumbers, shrimp, oysters, clams, mussels, and groundfish are all commercially harvested in the Puget Sound, accounting for $72 million in ex vessel value in 2006. Some of the commercial fish and seafood caught in the Puget Sound are shipped to other states and overseas. Oyster aquaculture is also practiced in Puget Sound's estuaries and bays, giving additional income to its residents. Successful oyster farms require intact systems which provide food and clean water to cultured shellfish. Kelp is recreationally harvested in Washington in April and May.

Forests provide food and income to residents of the Puget Sound Basin. Berries, mushrooms, deer, and elk are gathered or hunted by tribal and non-tribal residents alike.

In addition, gathering mushrooms and floral materials has become a major income generator for many immigrant populations in the region.

Washington State produced 34 billion board feet of commercial timber harvest in 2006 (WDNR, 2006), mostly coming from State and private lands. Federal lands have been extensively harvested in the past but environmental, social, and legal limitations were reached on these lands by the early 1990s; they now account for a small portion of the regional timber harvest (Swedeen, 2004).

Agricultural lands in the Puget Sound Basin produced $1.1 billion worth of crops and livestock in 2002, the latest year for which data is available (USDA, 2002). Berries, peas, potatoes, flower bulbs, seeds, and dairy products are the major economic yields of Puget Sound farms. Berries are especially high value products for the region. Local vegetable production that is marketed directly to consumers through farmers markets and Community Supported Agriculture programs has been increasing over the past 10 years (Evergreen Fund Consultants, 2004).

Tables 3-5 show that many ecosystem types in the Puget Sound Basin environment are involved in provisioning services. Forests, rivers, agricultural lands, and pastures form the landward ecosystems involved in this service. While it is difficult to capture the interactions among ecosystems in valuation exercises, there are multiple lines of mutual influence among them. Similarly, estuaries and bays, mudflats, rock reefs, kelp beds, seagrass beds, and continental shelf waters are all part of the marine food web, and many food species rely on multiple ecosystems for their life history needs.

Water Supply

Water is supplied ultimately through the operation of the hydrological cycle, which is mediated by evapotranspiration of vegetation on land. Over 60 percent of the world's population gets its drinking water from forested watersheds (UNEP, 2005). Loss of forest cover is associated with decreases in water supply due to lower ground water recharge and to lower reliability of flows (Vorosmarty et al., 2005). The Puget Sound Basin is heavily affected by its proximity to the Pacific Ocean and by the influence of the Olympic and Cascade Mountains. Ecosystems capture precipitation in the form of rain and snow. Water is filtered through forests and other vegetation into ground water and surface waters from which residents of the Puget Sound receive their drinking water, water for agriculture, and for industry. The city of Seattle has protected its upstream watersheds in the Cedar and Tolt watershed since 1899 (Seattle Public Utilities 2008). These two watersheds provide almost all of the water for 1.3 million residents and businesses located in Seattle. One way in which to understand the economic value of intact forested watersheds then is to compare it to the cost of building and maintaining water supply and treatment facilities. To the extent that loss of ecological systems results in reduced supply, value can also be ascertained through the cost of having to import water from elsewhere. These are examples of what economists call replacement costs (see section on valuation methods below).

Regulating Services

Regulating services are those that tend to keep natural disturbances dampened compared to what they would be without a particular ecosystem. For example, wetlands absorb wave energy from storms, thereby reducing the damage to nearby human structures. Large areas of forest cover contribute to a stable make up of gases in the atmosphere – a make-up that humans and other organisms have adapted to. Intact ecosystems also tend to keep disease organisms in check while degraded systems help propagate these organisms to the detriment of human health (UNEP, 2005).

Storm Protection

Estuaries and bays, coastal wetlands, headlands, intertidal mudflats, seagrass beds, rock reefs, and kelp forests provide storm protection. The same wave energy absorption capacity of these areas also dampens the energy of powerful waves from storm events. Estuaries, bays, and wetlands are particularly important for absorbing flood waters (Costanza et al., in review; UNEP, 2005).

Storm events that come across the waters of Puget Sound and the Strait of San Juan de Fuca are part of normal weather patterns that may become more frequent and more intense with climate change. Where significant infrastructure exists and where wetlands and wave-absorbing structures in the nearshore environment have been lost, higher levels of property damage could already be occurring as a result of this diminished ecosystem service. Thus, storm protection is an important ecosystem service for residents living close to the ocean-front or in other flood-prone areas. Given that significant infrastructure can be damaged during large storm events, tourism and recreation could be harmed as well. Puget Sound estuaries have lost about 60 percent of their salt marshes since European settlement (Buchanan et al., 2001).

Forests also provide storm protection by slowing down wind speeds. The Puget Sound area is very susceptible to wind storms from the coast and from the north. Large forested areas reduce the force that winds carry thus reducing potential damage to structures in urban areas. To the best of our knowledge however, no studies have been conducted that quantify the value of wind force reduction of forests.

Flood Protection

Wetlands and intact riverine floodplains, including riparian forests, absorb increased river flows during storm events and high snow-melt. Upland forests also absorb rainwater, reducing its downhill flow into major stream and river systems. As wetlands are lost, riparian areas disconnected from rivers and streams, and forest land replaced by houses and commercial development, more water flows overland during winter storms, causing more flood damage (Kresch and Dinicola, 1997). As noted above, the amount of pavement in Puget Sound counties has increased by over 10 percent in the past 15 years. The U.S. Geological Survey estimates that urban development leads to increases in flood peak discharges flows of 100-600 percent for 2-year storm events, 20-300 percent for 10-year events, and 10-250 percent for 100-year events (Konrad, 2003). One local study found that wetlands provide over $40,000 per acre of flood damage protection in Renton

(Lechine, 1997). A recent pilot study for King County demonstrated that flood hazard reduction projects that reconnect river and floodplain along the Cedar River could avoid between $468-22,333 per acre per year in damages to homes and county flood control facilities (Swedeen and Pittman, 2007). Retention of forest cover and restoration of floodplains and wetlands provide a tangible and valuable ecosystem service in terms of reduced damage from floods to property, lost work time, injury, and loss of life.

Shoreline Stabilization

Estuaries and bays, rocky islets, headlands, intertidal areas, rock reefs, sea grass, and kelp beds all buffer against wave energy. Shorelines are built and maintained naturally with interactions of the physical aspects of these structures, wave energy, tides, and sediment deposition. The biota in mudflats and nearshore soft bottom sediments also play a key role in maintaining the structure of sediments and preventing erosion (Weslawski et al., 2004). When these features are removed or significantly altered, dramatic changes and loss of shorelines can occur. Coastal wetlands and natural processes of land accretion are also very important for maintaining the line between land and sea, especially in the face of rising sea levels. Loss or sudden change in shoreline can result in private property damage, public infrastructure damage, loss of wildlife habitat, and in extreme cases, loss of life. Coastal erosion is a natural process along the Puget Sound's shoreline. However, changes in the habitat types listed above plus shoreline development have created multiple hazard areas. Approximately one third of the shoreline has been impacted by bulkheads, which leads to erosion in adjacent areas and an interruption of natural material accretion processes. Thus, retention of ecosystem features that stabilize the shoreline helps reduce the cost of engineered stabilization efforts, maintains habitat for species that use beach and nearshore ecosystems, and retains space for recreation and aesthetic enjoyment of the Sound.

Water Flow Regulation

The amount and timing of water flow in the Puget Sound Basin is important for many reasons. These include providing adequate amounts of cool water at critical times for salmon migration, provision of drinking and irrigation water, and maintenance of adequate flows to generate electricity from hydroelectric dams. Forest cover, riparian vegetation, and wetlands all contribute to modulating flow of water through upland portions of watersheds and into streams and rivers and finally into the Sound. Agricultural and urban development that removes forest cover and removal of riparian vegetation are the most important causes of loss of fresh water flow to coastal wetlands and bays. When forested basins are heavily harvested so that they are dominated by recently clear-cut or young stands, less water is absorbed by trees and the litter layer on the forest floor and more water flows overland into streams and rivers. This contributes both to higher peak flows and flood events (Moore and Wondzell, 2005). It also leads to a loss of the ability of forests to slowly release water during dry summer months, leading to lower stream flows and higher stream temperatures. Riparian vegetation in otherwise agricultural or developed landscapes also contributes to modulating stream flows. Coastal fresh water wetlands form a salinity gradient with saltwater marshes and the ocean. These freshwater wetlands keep salt water from intruding on coastal freshwater supplies, both at the surface and in aquifers (UNEP, 2005, Vol. 1, Chapter 19). Alteration of hydrology by diverting water to estuaries is considered to be a major threat to coastal areas (Pringle, 2000). Hypersalinization can occur when too much fresh water is prevented from reaching estuaries, threatening not only fresh water supplies but the several other services that estuaries provide.

Waste Processing

Microorganisms in sediments and mudflats of estuaries, bays, and nearshore submerged lands breakdown human and other animal wastes (Weslawski et al., 2004). They can also detoxify petroleum products. The disruption of the ecology of these organisms by physical destruction of habitat, alteration of food webs, or overload of nutrients or waste products also disrupts its disease regulation and waste processing services. Alteration of ecosystems can also create breeding sites for disease vectors where they were non-existent. People can be exposed to disease in coastal areas through direct contact with bacterial or viral agents while swimming or washing in fresh or marine water, ingesting contaminated fish, seafood, or water. Cholera outbreaks in coastal areas, recently on the rise in the southern hemisphere, are associated with degradation of coastal ecosystems (UNEP, 2006). The Puget Sound has had several incidents of shellfish and beach closures due to red tide and amnesic shellfish poisoning in recent years (Woods Hole Observatory, 2006). While the algae that cause toxic blooms are native to west coast waters and toxic blooms can occur as natural events, there are concerns and direct evidence that increasing pollution loads and climate change exacerbate the conditions that lead to toxic blooms (see Rabalais, 2005 for a summary). Many areas in Puget Sound also have health advisories due to high bacteria counts from human and domestic animal waste, especially in late summer, and many shellfish harvest areas have had to be closed (PSAT, 2007). Reduced access to beaches, fish, and shellfish due to disease has obvious impacts to human health and economic activity in the Puget Sound counties.

Wetlands, estuarine macroalgae, and nearshore sedimentary biota play a crucial role in removing nitrogen and phosphorous from water (Garber et al.1992, Weslawski et al. 2004). Removal of these nutrients maintains offshore water conditions conducive to native fish and invertebrate biota. Nutrient overload and hypoxic zones have become a major issue in Hood Canal in recent years from a combination of agricultural run-off, failed septic systems, and dumping of fish carcasses (PSAT, 2007). Land use patterns also play an important role. Researchers have found that more agriculturally and urbanized heavy watersheds contribute three times the nitrogen and phosphorous loads to the Puget Sound than the forested watershed of the Olympic Mountains (Embrey and Inkpen, 1998).

Gas Regulation

Gas regulation refers to the role that ecosystems play in regulating the gaseous portion of nutrient cycles which affect atmospheric composition, air quality, and climate regulation. Although carbon sequestration is a subset of this service, we are discussing it in a separate section because of its importance. Forests and individual trees play an important role in regulating the amount of oxygen in the atmosphere and in filtering pollutants out of the air, including removal of tropospheric ozone, ammonia, sulfur dioxide, nitrogen oxide compounds (NO_x), carbon monoxide, and methane. Removal of forests and other vegetation and biomass burning reduces air quality and contributed to global climate change.

American Forests (1998) calculated that urban forests remove 78 million pounds of pollutants per year in the Puget Sound area. Based on the value of avoided health care costs and other externalities, the authors valued this gas regulation service at $166.5 million per year for the year of 1996. The extensive forest cover of the entire Puget Sound Basin thus likely provides a significant amount of gas regulation services that is very valuable in terms of public health.

Carbon Sequestration

Carbon sequestration is a specific and important type of gas regulation. Forests, agricultural lands, wetlands, and marine ecosystems all play a role in carbon sequestration. Undisturbed old growth forests have very large carbon stocks that have accumulated over thousands of years. Replacing old growth forests with tree plantations results in net carbon emissions caused by the loss of hundreds of years of carbon accumulation in soil carbon pools and large live and dead trees (Harmon et al., 1990). Managed forests have the potential to sequester carbon that approaches old growth levels, but this requires longer rotations than current industrial standards and structural retention after each harvest (Marks and Harmon, 2002). Agricultural soils can also sequester carbon, especially when low or no tillage practices are employed (West and Post, 2002).

Marine life, particularly phytoplankton and marine benthic organisms play a crucial role in the global carbon cycle. The function of the ocean food web turns dissolved bicarbonate into solid form (skeletons and exoskeletons of plants and animals), which fall to the ocean floor. Sedimentation and benthic organisms sequester carbon in sediments. Geologic processes, such as dewatering, time, pressure, and heat convert sediments into sedimentary rock and move carbon from the biosphere to the lithosphere. This allows more CO_2 to be dissolved into ocean waters, keeping atmospheric CO_2 levels lower than they would be without life and oceanic biological and geological processes (Peterson and Lubchenco, 1997). The composition of phytoplankton diversity oxygen affect this process as some species are more palatable to marine grazers than others, thus determining the amount of uptake and pumping of carbon to the ocean floor (UNEP 2005, Vol. 1, Chapter 11). In addition, the availability of oxygen in oceanic basins regulates carbon retention in sediments. This is another important connection between biological diversity, ecosystem services, gas regulation, and topography.

Management actions to maintain the ability of the entire food web to function properly contribute to carbon sequestration. Coastal and estuarine wetlands also sequester carbon through photosynthesis and long term storage in wetland soils. In fact, wetlands may rival or outperform temperate forests and agricultural sequestration projects under some circumstances (Boumans et al., unpublished paper).

Supporting Services

The delivery of all other ecosystem services, depends on supporting services. These include basic functions of ecosystems such as primary production, nutrient cycling, and soil formation (UNEP, 2005, Vol. 1, Chapter 1).

Nutrient Cycling

There are 22 elements that are essential to the growth and maintenance of living things on earth. Some of these elements are only needed by a small number of organisms or in small amounts in specific circumstances, but the major planetary nutrient cycles of carbon, nitrogen, phosphorous, and sulfur are needed in relatively large quantities by all living things. These are the cycles that human actions have most affected. Silicon and iron are also important elements in ocean nutrient cycles because they affect phytoplankton community composition and productivity. It is living things that facilitate the movement of nutrients between and within ecosystems and turn them from, for instance, biologically unavailable forms such as rocks or the atmosphere into forms that can be used by others. Without functioning nutrient cycles, life on the planet would cease to exist.

Nutrient cycling is mediated by living organisms. On land, plants depend on biologically mediated breakdown of organic matter to make nutrients they need for growth available. As plants and plant parts die, they contribute to the pool of organic matter that feeds the microbial, fungal, and micro-invertebrate communities in soils that facilitate the transformation of nutrients from one form to another. Larger animals play a role in nutrient cycles through movement of nutrients from one place to another in the form of waste and, after they die, in the form of their bodies. Animals also play a crucial role in transporting nutrients between terrestrial, freshwater aquatic, and marine realms. Salmon and marine birds bring marine nutrients into terrestrial and freshwater ecosystems, enhancing the productivity of these systems throughout several trophic layers of the food web (Cedarholm et al., 2001; Polis et al., 1997). Forests play a very significant role in global nutrient cycles because they hold such large volumes of the basic nutrients and keep them within the system, thus buffering global flows. Deforestation has played a large part in altering global carbon and nitrogen cycles (Vitousek et al., 1997).

The marine role in the carbon cycle in terms of its significance for climate change was briefly described above. The marine environment plays a central role in all major global nutrient cycles. The movement of nutrients is also important locally and regionally for ecosystem productivity. Nutrient cycling takes place at multiple scales in the marine environment, from bacteria and other microorganisms in sediments in estuaries, shelf, and deep sea floors all the way to the global scale of ocean current patterns. Marine organisms fix nitrogen and take up carbon, phosphorous, and sulfur from the water or from other organisms. Much of the mass of these macronutrients is deposited in sediments where it is either stored for the long term, or is taken back up to surface waters by upwellings. Phosphorous, nitrogen, and carbon cycles are interlinked in marine environments and their relationship depends on whether sediments are oxygen-rich (oxic) or oxygen-poor (anoxic). These conditions are in turn affected by organism composition and external nutrient loads.

Changes to benthic communities can therefore have significant impacts on nutrient cycling capacity of organisms in these communities. Changes come from invasion of non-native species, physical disruption of habitat through dredging of waterways for navigation and bottom-trawling, overloading of nutrients beyond the capacity of the system to absorb, and changes to the food web caused by trophic cascades after removing top predators (Snelgrove et al., 2004 and references therein).

Removal of forests, riparian areas, and wetlands has had a significant effect on nutrient cycles. These ecosystems trap and retain nutrients that would otherwise run off into streams and rivers, and eventually end up in the ocean. The combination of increased use of fertilizers with loss of the buffering capacity of these ecosystems had lead to fresh water, estuarine, and ocean systems suffering nutrient overloads. Nutrient overloads lead to phytoplankton blooms above normal levels. As phytoplankton die and sink to the ocean floor, they consume most of the available oxygen, causing resident marine life to leave or die. Loss of commercially, recreationally, and culturally important fish species has occurred as a result. The number of marine dead zones in the world has doubled every decade since the advent of nitrogen fertilizers after World War II (UNEP, 2005). The presence of these dead zones is a clear indication that global nutrient cycles have been severely altered by human actions.

Nutrient cycling is a supporting service because many other services depend on it. Given that ecosystem productivity would cease without it, and is impaired when these cycles become significantly altered, nutrient cycling is a fundamental precursor to ecosystem and economic productivity. However, due to this fundamental role that cannot be fully substituted by human-made solutions, and because they operate at multiple overlapping scales, it is difficult to arrive at an accurate economic value for these services (Farber et al, 2006). Both production function and replacement cost methods (see further explanation of these methods below) deal with the problem of input prices being inaccurate due to subsidies of agricultural production and energy costs of producing fertilizers (thus market prices of goods do not reflect real marginal costs). Thus, attempts to value nutrient cycles economically usually produce underestimates. Given that such cycles are fundamental to the operation of life on the planet, this is one class of ecosystem services for which economic policy tools should only be used after biological limits to their functioning are used to set acceptable conditions external to the market (see scale discussion above).

Habitat

Habitat is the biophysical space, i.e., the juxtaposition of physical structure, adequate food availability, chemical and temperature regimes, and protection from predators, in which wild species meet some or all of their life needs. Refugium functions are sometimes distinguished from nursery habitat. A refugium refers to general living space for organisms while nursery habitat is specifically habitat where all the requirements for successful reproduction occur (De Groot et al. 2002). Tables 3-5 list all the ecosystem types in the Puget Sound Basin. Habitat provides the places where biological diversity and commercially and culturally important species are maintained. In addition to the physical structure provided to species, food web relationships are important components of habitats that support all species. For instance, food webs based on kelp and eel grass beds provide the conditions necessary for salmon, crab, sea cucumbers, and sea urchins – all commercially important species in the Puget Sound (Mumford, 2007).

All terrestrial, fresh water aquatic, and marine habitat types in the Puget Sound Basin have suffered degradation through physical alteration (from development, conversion from a natural to a heavily managed type, and logging), pollution, or the impact of invasive species (Buchanan et al., 2001; EPA, 2007; Olson et al. 2001). Loss of non-federal forestlands to residential and commercial development has been occurring at a rate of 1.04 percent per year from 1998 through 2004 (University of Washington College of Forest Resources, 2007). Toxic and biological pollution continue to pose a threat to nearshore and pelagic habitats and their associated species in the Puget Sound (PSAT, 2007). Habitat contributes significantly to other ecosystem services, namely, fisheries, recreation through wildlife watching, and cultural or spiritual values that are often expressed though people's willingness to pay for protection of natural areas and public or private expenditures on acquiring and protection habitat.

Pollination

Pollination refers to the role that insects, birds, and mammals play in transporting floral gametes, (e.g., pollen grains) (De Groot et al., 2002). Pollination is important to wild plants that people depend on directly for food and fiber and indirectly as part of ecosystem productivity. Many plant species would go extinct without animal and insect mediated pollination. Pollination services by wild animals are also crucial for crop productivity for many types of cultivated foods, enhancing the basic productivity and economic value of agriculture (Nabhan and Buchmann, 1997). The importance of wild pollinators to food crops means that wild habitats near croplands are necessary to provide sufficient habitat to keep populations of pollinators intact. The loss of forestlands and native shrubby riparian areas in suburbanizing rural areas has an impact on the ability of wild pollinators to perform this service. As has been noted above, loss of forest and farmland in the Puget Sound lowlands continues to be a concern, and likely affects the natural pollination functions of forests and riparian areas.

Primary Productivity

Primary productivity is another supporting service upon which all other ecosystem services depend. It refers to the conversion of energy from sunlight into forms that are used by the vast majority of living organisms. Plants on land and in fresh and marine water perform this function, using the sugars that are a product of photosynthesis for their own respiration. All other life forms eat plants, animals that eat plants or the decaying matter of dead plants and animals. Human life depends directly on primary productivity through consumption of crops, wild plants, seaweeds, fish and seafood, and livestock. We used to depend directly on the current energy flow from food consumption to conduct the work of survival and reproduction, then with the help of draft animals and simple machines. Since the onset of industrial age, humans have increasingly depended on fossil fuels which are ancient stored energy from photosynthesis. Since humans started to perform work using fossil fuels, the number of people and amount of consumption has far exceeded what would have been possible just by operating on current energy flows. Humans appropriate over 40 percent of the planet's terrestrial primary productivity. This share is increasing with massive ecological implications for the rest of planet's organisms and energy budget (Vitousek et al., 1986; Pimm, 2001). One likely consequence is a loss of biological diversity, which, as discussed above, would have severe consequences for the delivery of many other ecosystem services.

For ocean ecosystems, about 8 percent of total primary productivity supports human fisheries. However, when the calculation is confined to the parts of the ocean where most primary productivity and fish catches occur, the number approaches the proportion for terrestrial systems, at 25-30 percent (Pauly and Christensen 1995, Pimm, 2001). Again, if humans consume most ocean primary productivity in the form of fish and seafood, not much is left to fuel the remainder of the food web and all the ecological processes that it drives (Pimm, 2001).

Terrestrial primary productivity comes mainly from forests but other ecosystem types such as grasslands and meadows also contribute, although at a much lower rate. Loss of forests to development decreases primary productivity. Such loss is an issue in the Puget Sound Basin, especially in the suburbanizing fringe.

Marine primary productivity comes from wetland plants, macroalgae, and sea grasses in the coastal and nearshore environment, and from phytoplankton on the continental shelf and deep sea waters. Most marine primary productivity occurs in the coastal zone out to the extent of the continental shelf. Due to changes in currents and upwellings and changes in water chemistry that may affect the ability of diatomaceous phytoplankton to form calcerous shells, climate change has large implications for ocean primary productivity (Orr et al., 2005).

Cultural Services

Cultural services refer to the way in which ecosystems support non-material human activities that are socially significant. These include spiritual enrichment, cognitive development, reflection, recreation, and aesthetic appreciation (UNEP, 2005).

Aesthetic Value

Aesthetic value as an ecosystem service refers to the appreciation of and attraction to beautiful natural land and seascapes (De Groot et al., 2002). The existence of National Seashores, State and National Parks, Scenic Areas, and officially designated scenic roads and pullouts attest to the social importance of this service. There is also substantial evidence demonstrating the economic value of environmental aesthetics through analysis of data on housing markets, wages, and relocation decisions (Palmquist, 2002 and see studies included in valuation results below). Puget Sound's islands, rocky beaches, and views of water, forests, and mountains, are of major importance to the cultural and economic character of the region. There is also evidence substantiating the intuition that degraded landscapes are associated with economic decline and stagnation (Power, 1996).

Tourism and Recreation

Tourism and recreation are related to but not totally encompassed by aesthetic values. People travel to beautiful places for vacation, but they also engage in specific activities associated with the ecosystems in those places. Recreational fishing, scuba diving, surfing, kayaking, whale and bird watching, hunting, enjoying local seafood and wines, and beachcombing are all activities that would not occur or be thoroughly enjoyed without intact shorelines, fish and wildlife populations, clean water and without the aesthetic quality of the place. Storm protection, shoreline stabilization, and waste treatment are also important ecological services associated with recreation and tourism because they help keep tourists safe and protect both private and public infrastructure needed for the tourist industry.

Tourism and recreation, significant parts of nearly all coastal economies throughout the world, are both a blessing and a curse. Development designed to attract tourists has been a major source of degradation in coastal environments causing water quality and habitat degradation (UNEP, 2006). Too much recreational fishing pressure and too many whale-watching boats can also put excessive pressure on the species that attract people in the first place. The concept of ecotourism has arisen in part to deal with these issues. It is, however, an incomplete solution to date (UNEP, 2005; 2006).

Recreation and tourism are, like aesthetics, an important part of the link between ecosystem services and the Puget Sound's economy. Nearly 80% of the state's revenue generated by tourism is generated in the Puget Sound (Office of Financial Management, 2007). Over half of recreational salmon caught in Washington are from the Puget Sound (Puget Sound Partnership, 2007). Recreational fishing brings in substantial revenue to the state (approximately $500,000 in 2006 according to the Washington Department of Fish and Wildlife), and thus to the Puget Sound area. Healthy, fishable salmon populations are therefore important to the tourist economy. Whale and orca watching are also very popular tourist activities in the northern Puget Sound, with an estimated half a million visitors coming to see this population yearly (The Whale Museum, 2006). As Orca populations become increasingly stressed, and because the southern resident population is now listed as endangered, more restrictions are being contemplated for whale watching boats. Healthy marine wildlife populations are important not only in and of themselves, but as a source of income for several businesses in the Puget Sound.

Likewise, scuba diving, kayaking, bird watching, hiking, climbing, and nature photography draw people, both residents and visitors, to the natural areas of the Basin. The Washington Department of Fish and Wildlife calculated that wildlife watching in Washington State brought in $980 million in 2001 (WDFW, 2002). It is interesting to note that in the year for which these spending statistics were reported, non-consumptive wildlife-viewing accounted for more than double the expenditures for hunting and exceeded recreational fishing spending by nearly $130 million. While not all of this spending occurred in the Puget Sound Basin, statistics on the proportion of overall tourism revenue generated in Washington that comes from the Puget Sound indicates that well over half of this was likely spent in the region. The State of Washington has also invested in ensuring that people have public access to the 35 State Parks located in the region. Washington does not charge users fees for these parks, indicating that it is willing to spend considerable fiscal resources to support outdoor recreation.

While teasing out the direct monetary contribution of the ecosystems themselves to the recreation and tourism economy, there is no doubt that attractive landscapes, clean water, and healthy fish and wildlife populations provide a necessary underpinning to this sector of the economy. Several studies of nature-related recreation are included in the ecosystem service value analysis described below.

Other Cultural Services

Other aspects of the linkage between ecosystem and culture include the spiritual significance that individuals and societies place on nature and the scientific and educational value derived from studying natural systems. As is evidenced by their traditions around salmon and other marine organisms and by their art and stories, the marine environment is especially important from a spiritual perspective to tribal communities in the Pacific Northwest. Individuals of non-native origin also express the spiritual value of nature through various means. One important aspect of attempting to ascribe economic value to spiritual significance should be noted here. The use of willingness to pay surveys (see below for definitions) for things like saving whales or spotted owls reveals that many people are unwilling to trade money or tangible goods for the loss of species or places; they rank the protection of nature above many aspects of material well-being, some respondents to such survey instruments give "protest bids" or indicate that they are not willing to put a price on saving wildlife or wild places (see Spash, 2005 for a review). The standard assumption in economics about humans is that we are willing to trade any object in a bundle of goods for anything, including monetary compensation. The documentation of behavior to the contrary demonstrates that there is difficulty, and sometimes cultural aversion, to attempting to assign monetary value to all aspects of ecosystems and their services.

Scientific and educational importance of ecosystems is evidenced by the number of educational and research institutions devoted to studying marine and terrestrial environments. Government, academic, and private resources are all devoted to formal study of ecosystems in the Puget Sound Basin. Such pursuits benefit people through direct knowledge gained for subsistence, safety, and commercial purposes. The study of natural systems is also an important intellectual pursuit for helping people understand how complex systems work. Scientific and educational institutions devoted to both marine and terrestrial environments also provide locally significant employment. These institutions include Batelle Northwest, University of Washington biology and forestry schools, The Pacific Northwest Research Station of the U.S. Forest Service, and NOAA Pacific Fisheries Science Center.

PART 2: Valuation of Puget Sound Basin Ecosystem Services

Valuation of Ecosystem Services Background

The economy of the Puget Sound Basin cannot be understood without examining the contribution of natural capital and its associated flows of ecosystems services to the economy and well-being of people. Our economy and communities reside within the landscape as part of the environment. However, most decisions are made without considering the explicit contribution of functioning ecosystems to economic activity and output. Interest in identifying, describing, and quantifying the economic value of ecosystem services has grown tremendously over the past 20 years, expressly for the purpose of improving environmental decision making (Daily 1997, Costanza et al. 1997b, Balmford et al. 2002). This is particularly relevant for coastal areas. Rough and preliminary estimates of the global economic value of coastal and nearshore marine ecosystems demonstrated that two-thirds of total ecosystem service value of all systems on earth come from coastal and marine systems (Costanza et al., 1997b, Costanza 1999). Understanding the nature of this economic value and how it changes with ecosystem restoration or degradation is also crucial because coastal systems are under great development and extraction pressure relative to other biomes (UNEP 2005, Vol. 1, Ch. 19).

Ecosystems produce goods and services. Ecosystem goods like fish or trees can be excludable and amenable to market pricing while ecosystem services like the production of climate protection, or hurricane storm protection are public services, non-excludable, and not amenable to market pricing. Markets for fish and timber can exist because people can be excluded; once a fish is caught, nobody else can catch that same fish. Markets for breathable air cannot exist because people cannot be excluded from breathing air. In addition, breathing air is not rival; a person's breathing does not restrict another's breathing. Roads are rival; we all have equal access to roads, however, having too many people on the road restricts its effective use. Air is neither excludable (cannot be owned) nor rival (everyone can breathe the air). Every specific ecosystem good or service has special physical qualities which determine if it is an excludable or rival good or service and how well market valuation fits the nature of that service.

Ecosystem functions and the services they produce are diverse and operate across large landscapes (storm buffering) or, in some cases, the whole planet (carbon sequestration). Highly interdependent physical and biological systems make life, and economic life, on the planet possible – the operation of climate, oxygen production, nutrient cycles, water and energy flows, the movements of seeds, pollen, and pollinators, the distribution of different types of plants and soils, biodiversity, and the availability of decomposer organisms, such as bacteria, to clean up natural waste products. Oceans operate in a similar way with some organisms spanning large parts of the globe, and ocean nutrient cycles taking place over very large spaces and long time frames.

Because ecosystems provide a tremendously valuable, wide variety of common wealth, public goods, and services at least cost over long periods of time, they are the best systems for producing these goods and services. It would be impractical, in some cases impossible and simply undesirable, to replace these economically valuable natural systems with more costly and less efficiently-built capital substitutes.

Valuing services which are "public goods" that are not excludable and thus unmarketable, but do contribute to our common wealth, is difficult. However, a number of techniques have been developed to derive economic values for ecosystem services.

Valuation Techniques

Ascribing economic value to these ecosystem services helps policy makers and the public decide how to allocate public funds for the common good upon which private wealth depends (Costanza, 2006). Ecosystem goods and services may be divided into two general categories: ***market*** and ***non-market***. Measuring market values simply requires monitoring market data for prices and quantities sold. This production creates a flow of ecosystem goods that have a market-defined economic value over time.

Non-market values of goods and services are more difficult to measure. When there is no explicit market for services, more indirect means of assessing values must be used. Table 6 identifies a spectrum of valuation techniques that are commonly used to establish values when market values do not exist.

Table 6. Valuation Methodologies

Avoided Cost (AC): services allow society to avoid costs that would have been incurred in the absence of those services; storm protection provided by barrier islands avoids property damages along the coast.
Replacement Cost (RC): services can be replaced with man-made systems; nutrient cycling waste treatment provided by wetlands can be replaced with costly treatment systems.
Factor Income (FI): services provide for the enhancement of incomes; water quality improvements increase commercial fisheries catch and the incomes of fisherfolk.
Travel Cost (TC): service demand may require travel, whose costs can reflect the implied value of the service; recreation areas attract distant visitors whose value placed on that area must be at least what they were willing to pay to travel to it, including the imputed value of their time.
Hedonic Pricing (HP): service demand may be reflected in the prices people will pay for associated goods; for example, housing prices along the coastline tend to exceed the prices of inland homes.
Marginal Product Estimation (MP): service demand is generated in a dynamic modeling environment using a production function (Cobb-

Douglas) to estimate the change in the value of outputs in response to a change in material inputs.
Contingent Valuation (CV): service demand may be elicited by posing hypothetical scenarios that involve some valuation of alternatives; for instance, people generally state that they are willing to pay for increased preservation of beaches and shoreline.
Group Valuation (GV): this approach is based on principles of deliberative democracy and the assumption that public decision making should result, not from the aggregation of separately measured individual preferences, but from *open public debate.*

Table 7 summarizes the appropriateness of each technique for different types of services. The abbreviations in the third column of Table 7 refer to the valuation methodologies provided in Table 6.

Table 7. Appropriateness of Valuation Methodologies for Ecosystem Service Type[2]

Ecosystem Service	Amenability to Economic Valuation	Most Appropriate Method for Valuation	Transferability Across Sites
Gas regulation	Medium	CV, AC, RC	High
Climate regulation	Low	CV, AC, RC	High
Disturbance regulation	High	AC	Medium
Biological regulation	Medium	AC, P	High
Water regulation	High	M, AC, RC, H, P, CV	Medium
Soil retention	Medium	AC, RC, H	Medium
Waste regulation	High	RC, AC, CV	Medium to high
Nutrient regulation	Medium	AC, RC, CV	Medium
Water supply	High	AC, RC, M, TC	Medium
Food	High	MP	High
Raw materials	High	MP	High
Genetic resources	Low	M, AC	Low
Medicinal resources	High	AC, RC, P	High
Ornamental resources	High	AC, RC, H	Medium
Recreation	High	TC, CV, ranking	Low
Aesthetics	High	H, TC, CV, ranking	Low
Science and education	Low	Ranking	High
Spiritual and historic	Low	CV, ranking	Low

Source: Adapted from Farber et al 2006

[2] This table, adapted from Farber et al. 2006,- reflects our opinion of the appropriateness of some techniques for some services that differ from the original authors.

Tables 6 and 7 show that each valuation methodology has its own strengths and limitations; often restricting its use to a select range of ecosystem goods and services within a given landscape. For instance, the value generated by a naturally functioning ecological system in the treatment of wastewater can be estimated by using the replacement cost (RC) method which is based on the price of the cheapest alternative for obtaining that service (the cost of chemical or mechanical alternatives). Avoided cost (AC), which is a related method, can be used to estimate value based on the cost of damages due to lost services. This method was used to value the flood protection services provided by restored habitats and functions within the flood plain. Travel cost (TC) and contingent valuation (CV) surveys are useful for estimating recreation values while hedonic pricing (HP) is used for estimating property values associated with aesthetic qualities of natural ecosystems. Contingent valuation surveys and conjoint analysis can be used to measure existence value of ecosystems and charismatic animals. Marginal product estimation (MP) has generally been used in a dynamic modeling context and aids in examining how ecosystem service values change over time. Finally, group valuation (GV), a more recent addition to the valuation literature, directly addresses the need to measure social values in a group context. In many applications, the full suite of ecosystem valuation techniques will be required to account for the economic value of goods and services that a natural landscape provides. Note from the tables above that not all ecosystem services are readily valued and that some services have no valuation studies. Very important services such as climate regulation, genetic resources, and spiritual and historical significance, are of great value but have low valuation amenability. In addition, nutrient cycling as a basic supporting service usually receives relatively low values even though life on the planet would not be possible without it.[3] Because traditional economic valuation is based on marginal market values, valuation methodologies are not well suited to the valuation of natural systems that provision essential goods and services freely.

This inability to completely value ecosystem services was once of little consequence because the human economy was too small to disrupt major global systems such as climate and local natural systems appeared to be abundant. Today, this flaw in economic valuation presents society with tremendous challenges. The crux of sustainability is making the right investment decisions in natural and built capital (as well as human and social). With valuation techniques that easily value built capital but are poor guides to natural capital values society risks under investing in valuable natural assets and far worse losing those assets deteriorate at great cost to present and future generations.

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[3] UNEP 2005, Vol. 1, Chapter 12.

Conducting an "Appraisal" of our Natural Capital

While original studies are desirable for context and accuracy, such data are often simply not available within the desired time frame. Conducting original empirical work for all services and all ecosystem types in a study area would entail over 100 primary ecosystem service valuation studies and would be cost prohibitive. This study is intended to emphasize the importance of filling critical informational gaps in ecosystem service valuation. Greater primary research over the next few years will enable a sharper understanding of Puget Sound ecosystem services.

To address this difficulty, economists use a methodology that is similar to a house appraisal and is called value or benefit transfer (see below for a more detailed discussion of this method). The market value of a house before it is sold is not known. To estimate the value, an appraisal is conducted to determine a likely range of values. Appraisals are based on established values of other houses that are close by and share similar attributes. The particular aspects of the house, such as a good roof, the number of bedrooms, a finished basement, and a mountain view, are also considered in the appraisal. These attributes comprise additive values for estimating the appraised value of the house.

Similarly, a value transfer study uses values derived from studies of similar ecosystem types, the closer to the study site in location and attributes the better. However, studies from other parts of the country or world can be used to estimate the values in the target study area. More studies from distant areas broaden the low-high range estimate of values. Called the benefit transfer method, this is done by conducting a careful analysis of economic values for the appropriate ecosystem type, determining applicability to the target area, converting values to common units – usually dollars per acre per year – then applying them to acres of ecosystem type based on GIS analysis.

The wide ranges of value that can emerge from these studies and other issues involving incommensurability have resulted in a vigorous discussion in the academic literature on the use of benefit-transfer methods (see e.g., Wilson and Hoehn, 2006 and Spash and Vatn, 2006). While these studies have limitations, they provide valuable information in the appropriate context. The purpose of estimating ecosystem services is to provide a better valuation than the implicit value of zero. Estimates from value transfer studies have inherant uncertainty. By using the lowest estimates in the literature and the highest provides a range of values that should capture the value of the ecosystem services examined in the study area. The low valuation boundary, as in this case, are underestimates of actual value; they can demonstrate that ecological services in an area are worth at least a certain dollar amount which is usually sufficient to inform policy decisions such as restoring or maintaining those systems.

In addition, economic values are not the sole decision-making criteria. Techniques called multi-criteria decision analysis are available to formally incorporate economic values with other social and policy concerns (see Janssen and Munda, 2002 and de Montis et al., 2005 for reviews). Having economic information on ecosystem services usually helps this process because traditionally, only opportunity costs of forgoing development or exploitation are counted against non-quantified environmental concerns.

There are also social issues involved with the entire exercise of assigning monetary values to nature. Discussions of the economic value of ecosystem services are often laden with concerns of privatizing nature (e.g., McCauley, 2006) or worries that the act of putting dollar values on what ecosystems do will lead private landowners to demand payments for the services their lands provide without regard for wider social or legal obligations. It is important to frame the discussion of ecosystems and their services with an analysis of both the ecological economic and legal underpinnings of ecosystem services as public and/or common property resources (Barnes, 2006). Understanding that ecosystems have economic value does not mean that ecosystem services can or should be privatized. In fact, because most ecosystem services are non-excludable, public goods by nature (or by definition), they simply cannot be privatized and must fall under the remit of public institutions.

Perhaps most importantly, financial and investment decisions that are denominated in dollars are constantly being made, thereby allocating public and private money and resulting in a profound impact on natural capital systems and ecological and economic productivity. Establishing a range of value with the best available valuation methodology allows for the more effective inclusion of natural capital in budgetary, financial, and investment decisions.

Valuation of ecosystem services in Washington State is a relatively new field. There are few studies. Individual valuation studies are the basis for understanding how value is provided from a land cover type to people. These studies give a glimpse of value and are not comprehensive. The valuation of flood protection provided by wetlands, for example, (Leschine et. al., 1997) examines the value of wetlands in urban and rural areas. In Lynnwood, WA a community just north of Seattle, only 2% of wetlands are left, they are scarce and those left provide important services and are of greater value per acre than more abundant wetlands in upland areas. Leschine describes the value these urban wetlands between $36,000 in Lynnwood and $51,000 in Renton, a community just south of Seattle, another urbanized area. Wetlands in North Scriber Creek, a more rural area range from $8,000 to $12,000/acre. This study describes one vegetation type and one ecosystem services. A compilation of studies across different vegetation types and ecosystem services is required to understand the value of flood protection provided in a watershed composed of forests, grasslands, agricultural areas, urban land and wetlands. This is only representative of a number of studies that have been conducted in the Northwest on ecosystem services.

Currently, benefit transfer offers an imperfect but workable methodology for deriving an "appraisal" of the value of natural capital. This is a static approach, a snapshot of valuation at a specific time, with a set of GIS data and valuation studies. A dynamic systems analysis, such as that being developed by the University of Vermont Gund Institute (MIMES Project), in partnership with Earth Economics promises to provide a dynamic modeling directly connected to physical data. This allows an examination of change in physical conditions and changes in value over time. Scenarios with or without restoration can be examined. It also allows a spacially explicit mapping of ecosystem services, the mechanics of their provisioning and the systems delivering these services to beneficiaries.

In the development of another methodology, Earth Economics currently is co-principle with the University of Vermont Gund Institute For Ecological Economics (ARIES Project) on a National Science Foundation Grant which examines methodologies for linking studies that show the differences in the provisioning of flood services spacially across the landscape and how to utilize the diversity of information provided by valuation studies in conjunction with GIS information systems and an "ontology" or understanding of how these ecosystem services are provisioned.

Another project, the Natural Capital Project also seeks to map the provisioning of ecosystem services and the beneficiaries across the landscape.

The Puget Sound Nearshore Partnership produced several reports outlining benefits Puget Sound ecosystems provide. Leschine and Petersen (2007) provide a discussion of "valued ecosystem components" which incorporate aspects of social, cultural, spiritual, ecological and economic values. They also provide a discussion of ecosystem services and valuation techniques.

The fact remains, that there is a dearth of data (Plummer, 2007), analysis and methodology for accurately calculating the value of most natural capital, particularly services for which there are no markets.

Value Transfer Methodology

This study used the value transfer methodology which takes the results of previous studies, screens them for appropriate fit, then applies them to a target site which has very little or no coverage from original empirical studies (Devouges et al. 1998, Loomis, 1992). It is oftentimes the only feasible approach to a comprehensive valuation of ecosystem services in an area due to limitations of time and funds. Conducting all new empirical research for all ecosystem types and services in a particular region, especially an area as large and as diverse as the Puget Sound Basin, would take millions of dollars and many years to complete. Since it can be used to reliably estimate a range of economic values associated with a particular landscape, based on existing research, for considerably less time and expense than a new primary study, the value transfer method has thus become a very important tool for policy makers in the US and other countries.

Value transfer studies of large landscapes like the entire Puget Sound Basin by necessity aggregate peer reviewed valuation estimates using all or most of the techniques described in Tables 6 and 7. This is because such a large landscape will encompass many types of ecosystem services and not all services can be ascribed economic value using the same techniques or even family of techniques.

Using Geographic Information System (GIS) data for the Puget Sound Basin, the acreages of forest, grass and shrub, agriculture and pasturelands, wetlands, urban areas, lakes, ponds, rivers and streams, marine and estuarine waters, eel grass and ice and rock were multiplied by the estimated value production per acre, where reasonable values could be found, for each identified ecosystem services. Peer reviewed journal articles were reviewed for each GIS classification and the values associated with each ecological service. The high and low values for each ecosystem type and ecological service were selected to provide the high and low range estimates. A benefit transfer methodology was applied to the GIS data to calculate a range of dollar values of ecosystem services provided annually within the Puget Sound Basin.

One of the most comprehensive value transfer studies in the United States was recently conducted for the State of New Jersey (Costanza et al., 2007). The authors conducted a thorough literature review of valuation studies, screened them for appropriate demographic and economic variables, and converted all values to 2004 dollars per acre per year. They focused on 10 ecosystem services for which empirical studies were available and that are non-market in nature (as data is readily available for ecosystem goods which are sold in markets).

This study of the Puget Sound ecosystem services also applied the approach described in Costanza et al., 2007 and used the values published therein as a base point (in dollars per acre per year). Studies specific to ecosystems of the Pacific Northwest and Puget Sound that were not included in the New Jersey study were added here. Studies that were not appropriate to the Puget Sound were screened out. Low and high estimates are provided to give the range of variation on estimates for each ecosystem cover type and service combination. While this low and high range in estimates of ecosystem service values reflects the innate uncertainty in applying value transfer, it also provides a reasonably robust result.

Because this is a meta-study, utilizing many valuation studies, we do not know the cumulative shape of the error. However, both the low and high values established are likely underestimates of the full value of ecosystem services provided within the Puget Sound basin because values for most ecosystem services have not been estimated. In addition, for those ecosystem services for which we estimate a value, most have not been estimated across all vegetation types. Omission is still the greatest hurdle, and likely the greatest source of error in the valuation of ecosystem services.

The lower value boundary represents a “below the floor” value for natural capital and carries a great deal of confidence. It can be an important guidepost for policy.

To calculate the entire range of estimated values, the full list of estimated values available in the literature for a particular cover type ecosystem-service combination was reviewed.

Many individual valuation studies include low and high estimates. All the lowest estimates from each list of studies for each ecosystem service within a cover type were totaled to provide a low estimate with the same procedure to establish the high estimates. The estimates were not averaged. This approach results in a larger range than would be the case if all low (high) estimates within a cover type ecosystem service combination were first averaged prior to aggregating across ecosystem services within a cover type, however it better reflects the underlying uncertainty.

All studies from which estimates are derived were from temperate zone ecosystems and high income countries. In this way, estimates from ecosystem types with very different ecological parameters (e.g., tropical versus temperate forests) or from countries with very different income demographics (industrialized versus non-industrialized) were excluded. Most all of the studies were conducted in the United States. Appendix A lists the studies used for the value transfer estimates. All values were standardized to 2006 dollars using the Bureau of Economic Statistics Consumer Price Index Inflation Calculator.

GIS Data

The most recent (2006) National Land Cover Data (NLCD) from the U.S. Environmental Protection Agency was used as GIS data to define cover types to which value estimates were applied. The only cover type used in the analysis but not derived from GIS data is the extent of eel grass beds. This data came from surveys conducted by Washington State Department of Natural Resources and reported in Mumford (2007).

Table 8. Overall Land Cover Summary

OVERALL LAND COVER SUMMARY (NLCD)

NLCD Code	Description	Acres
0	Unclassified	2,766
11	Open water (total)	1,802,508
	River	15,905
	Lakes	106,000
	Estuary+Salt water	1,680,603
	Estuary	552,712
	Salt water	1,127,891
12	Perennial ice/snow	97,849
21	Developed open space	421,574
22	Developed low density	429,382
23	Developed medium density	167,844
24	Developed high density	66,678
31	Barren (rock/sand/clay) (total)	340,592
	Beach	48,341
	Non-beach	292,251
41	Deciduous forest	267,010
42	Evergreen forest	4,534,878
43	Mixed forest	677,680
52	Scrub/shrub	794,631
71	Grassland/herbaceous	320,443

81	Pasture/hay	307,242
82	Cultivated crops	73,266
90	Woody wetlands	174,132
	Saltwater woody wetlands	7,024
	Freshwater woody wetlands	167,109
95	Emergent herbaceous wetlands	124,918
	Saltwater herbaceous wetlands	76,120
	Freshwater herbaceous wetlands	48,798
Total		**10,603,394**

A hydrography layer (OR/WA Hydrography Framework Partnership. 2005) was used to identify the riparian area of the Puget Sound Basin within a 50 meter buffer. This was used to calculate the riparian forest and riparian shrub values. These areas were deducted from the total area of these vegetation classes in the NLDC figures to avoid double counting.

Table 9. Riparian Areas Using 50 m Buffer and DNR Hydrography

RIPARIAN AREAS - USING 50m BUFFER AND DNR HYDROGRAPHY LAYER		
NLCDCode	**Description**	**Acres**
0	Unclassified	66
11	Open water (total)	14,202
12	Perennial ice/snow	4,693
21	Developed open space	69,982
22	Developed low density	34,010
23	Developed medium density	8,472
24	Developed high density	2,792
31	Barren (rock/sand/clay) (total)	32,127
41	Deciduous forest	61,154
42	Evergreen forest	1,027,004
43	Mixed forest	162,159
52	Scrub/shrub	200,180
71	Grassland/herbaceous	55,429
81	Pasture/hay	36,762
82	Cultivated crops	10,812
90	Woody wetlands	58,917
	Eel grass beds	49,422
95	Emergent herbaceous wetlands	18,665
Total		**1,797,362**

Forests do not provide similar ecosystem services. Recently-logged areas cannot provide the same biodiversity, flood control, or water filtration benefits as older stands. To avoid overestimating the value of forests, five forest successional stages for the Puget Sound region were identified with their areas based on recent successional stage mapping data (Interagency Vegetation Mapping Project 2004). This data was provided as total forest acreage; coniferous, deciduous, and mixed forests could not be separated. This database does not match the NLCD for total forest acres. Thus, it was assumed that each of the forest classifications, including riparian, have the same ratio of stages in the NLCD database as the total forested area in the Interagency Vegetation Mapping Project. NLCD data in Table 8 was used to calculate the ecosystem services. Because logging in riparian areas is restricted, this assumption underestimates the actual successional stage for riparian areas, and thus underestimates the value riparian areas provide via the ecosystem services examined.

Table 10. Forest Successional Stage Summary

FOREST SUCCESSIONAL STAGE SUMMARY		
Size	**Stage**	**Acres**
0-4.9	Early successional	911,059
5-9.9	Pole	892,615
10-19.9	Mid successional	1,682,082
20-29.9	Late successional	931,873
30+	Old growth	758,458
TOTAL		**5,176,085.3**

The low and high values derived from the valuation literature for NLCD land cover classification examined by ecosystem service are listed in Table 8. Appendix A lists by ecosystem service and land cover classification the references for each of these values, as well as additional references for values falling between these low and high estimates.

A Puget Sound basin carbon sequestration calculation was made based on carbon sequestration rates described in Birdsey, 1996 and using the Chicago Climate Exchange figures for the low estimate ($4.40/ton) and a high estimate of $85/ton based on the 2006 Stern report, which would include climate externalities.

The following tables show the Low and High Estimates of the Value per Acre per Year of Ecosystem Services for Land Covers in the Puget Sound[4] in 2006 dollars.

[4] Open cells in the table indicate a lack of studies for a particular ecosystem service-cover type. Shaded cells indicate that a particular cover type is unlikely to provide an ecosystem service.

Table 11. High and Low Estimates For Forests

Ecosystem Service Values	Mid Forest Low	Mid Forest High	Late/Old Growth Forest Low	Late/Old Growth Forest High
Gas and climate regulation	$32.27	$623.39	$43.56	$841.50
Disturbance regulation				
Water flow regulation	$9.61	$9.61	$9.61	$9.61
Water quality				
Water supply				
Habitat refugium			$269.85	$500.24
Pollination	$31.49	$141.41	$62.97	$282.82
Soil erosion control				
Soil formation				
Biological control				
Nutrient cycling				
Aesthetic and recreational	$4.89	$318.91	$9.78	$637.81
Total by Cover Type	**$78.26**	**$1,093.32**	**$395.77**	**$2,271.98**

Table 12. High and Low Estimates For Riparian Pole and Forests

	Riparian Forest Low	Riparian Forest High	Riparian Pole Low	Riparian Pole High
Gas and climate regulation	$43.56	$841.50	$22.59	$436.34
Disturbance regulation	$7.56	$235.73		
Water flow regulation	$9.61	$9.61	$9.61	$9.61
Water quality				
Water supply	$2,105.00	$13,015.08		
Habitat refugium	$269.85	$500.24		
Pollination				
Soil erosion control				
Soil formation				
Biological control				
Nutrient cycling				
Aesthetic and recreational	$1,043.00	$10,624.14	$1,043	$10,624.14
Total by Cover Type	**$3,478.58**	**$25,226.30**	**$1,075.20**	**$11,070.09**

Table 13. High and Low Estimates for Fresh Wetland and Pole Forests

	Fresh Wetland Low	Fresh Wetland High	Pole Forest Low	Pole Forest High
Gas and climate regulation	$29.43	$267.53	$22.59	436.34
Disturbance regulation				
Water flow regulation	$6,357.71	$6,357.71	$9.61	$9.61
Water quality				
Water supply	$199.11	$31404.56		
Habitat refugium	$58.89	$12,537.14		
Pollination				
Soil erosion control				
Soil formation				
Biological control				
Nutrient cycling				
Aesthetic and recreational	$31.47	$9,347.33		
Cultural				
Total by Cover Type	**$6,676.61**	**$59,914.27**	**$32.20**	**$445.95**

Table 14. High and Low Estimates for Grassland and Agriculture.

	Grassland Low	Grassland High	Agriculture Low	Agriculture High
Gas and climate regulation	$3.85	$3.85		
Disturbance regulation				
Water flow regulation	$1.65	$1.65		
Water quality	$47.91	$47.91		
Water supply				
Habitat refugium				
Pollination	$13.77	$13.77	$2.40	$12.10
Soil erosion control	$15.97	$15.97		
Soil formation	$0.54	$0.54		
Biological control	$12.66	$12.66		
Nutrient cycling				
Aesthetic and recreational			$27.50	$27.50
Cultural				
Total by Cover Type	**$96.35**	**$96.35**	**$29.90**	**$39.60**

Table 15. High and Low Estimates for the Pasture and Rivers and Lake

	Pasture Low	Pasture High	Rivers and lakes Low	Rivers and lakes High
Gas and climate regulation				
Disturbance regulation				
Water flow regulation				
Water quality				
Water supply			$17.13	$834.44
Habitat refugium			$58.89	$1,479.84
Pollination				
Soil erosion control				
Soil formation	$6.22	$6.22		
Biological control				
Nutrient cycling				
Aesthetic and recreational	$0.03	$0.03	$1.69	$19,699.00
Cultural				
Total by Cover Type	**$6.25**	**$6.25**	**$77.71**	**$22,013.28**

Table 16. High and Low Estimates of Urban Green Space and Beaches

	Urban green space Low	Urban green space High	Beach Low	Beach High
Gas and climate regulation	$26.81	$874.79		
Disturbance regulation			$22213.11	$36,006.72
Water flow regulation	$5.72	$170.89		
Water quality				
Water supply				
Habitat refugium				
Pollination				
Soil erosion control				
Soil formation				
Biological control				
Nutrient cycling				
Aesthetic and recreational	$1,261.31	$3,697.42	$140.21	$45,521.29
Cultural				
Total by Cover Type	**$1,293.84**	**$4,743.10**	**$22,353.32**	**$81,528.01**

Table 17. High and Low Estimates for Estuaries and Salt Marshes

	Estuary Low	Estuary High	Salt marsh Low	Salt marsh High
Gas and climate regulation				
Disturbance regulation			$242.91	$95,951.00
Water flow regulation			$109.78	$17,673.84
Water quality				
Water supply	$5.90	$127.84		
Habitat refugium	$11.55	$1,385.51	$1.17	$1,017.08
Pollination				
Soil erosion control				
Soil formation				
Biological control				
Nutrient cycling				
Aesthetic and recreational	$1.17	$355.16	$4.88	$97.56
Cultural				
Total by Cover Type	**$18.62**	**$1,868.51**	**$358.74**	**$114,739.48**

Table 18. High and Low Estimates for Eelgrass Beds and Marine Water

	Eelgrass Beds Low	Eelgrass Beds High	Marine Water Low	Marine Water High
Gas and climate regulation				
Disturbance regulation				
Water flow regulation				
Water quality				
Water supply			$259.34	$772.68
Habitat refugium				
Pollination				
Soil erosion control				
Soil formation				
Biological control				
Nutrient cycling	$5,507.00	$15,421.00		
Aesthetic and recreational				
Cultural				
Total by Cover Type	**$5,507.00**	**$15,421.00**	**$259.34**	**$772.68**

Valuation Results

Based on available data, we estimate that the value of the flow of non-market ecosystem services is between \$7.4 and \$61.7 billion per year. Estimates of per acre per year values are given in Table 19, and the total value by ecosystem type are shown in Table 20. The highest per acre values are from the storm protection function of salt marshes (\$96,000), aesthetic and recreational values of beaches (\$45,000), disturbance protection from beaches (\$36,000), water supply from fresh water wetlands (\$31,400) and aesthetic and recreation values of rivers and lakes (\$19,700). All of these values are at the high range of estimates (versus low and average) for the particular ecosystem type/ecosystem service combination. High dollar values in most of these cases result from the proximity of high value homes and businesses to a regulation (i.e., protection function of the ecosystem). The exception is recreational value of rivers and lakes, where the estimate came from a relatively remote, hypothetically fully restored large river which attracted a wide variety of recreational uses. The highest value ecosystem type in total was mid to late seral forested riparian areas (\$20 billion per year at the high end) and fresh water wetlands (\$12 billion per year at the high end). These high total values arise as a result of the combination of the high per acre value and the geographic extent of the ecosystem type.

The lowest values come from agricultural lands and pasture, partially due to the fact that the value of marketed commodities was excluded because of this report's focus on services that are not traditionally considered. The total annual market value of agricultural production from crop and pasture lands in the Puget Sound counties was \$1.1 billion in 2002. We did not include early seral forests in Table 20 because we assigned them a value of \$0; ecosystems services that produce monetary value are in late seral and old growth forests (e.g., carbon sequestration, habitat, aesthetic and recreational). Mid-seral forests also provide some services. While recently clear-cut and young regenerating stands are obviously not biological deserts and retain the potential to increase their production of services, the flow and value are very low.

A quick glance at Tables 11-18 shows that there are large gaps in coverage of original empirical ecosystem service valuation studies. Of 192 possible cover-type ecosystem service value combinations, there are 118 for which no local data exists, but for which the service occurs and thus has positive value. For this reason alone, we think that the estimated range provided here of \$7.4 - 61.7 billion per year is a large underestimate of the range in total annual flows of value from ecosystem services benefiting the residents of the Puget Sound Basin. This large gap in coverage from empirical studies also underpins the caution that the entire approach of valuing ecosystem services is not yet complete enough to use results to make decisions regarding the trade-offs between one ecosystem type and another based on monetary value.

Table 19. Estimate of Summed Ecosystem Value Flows for the Puget Sound Basin

		Total $/ac/yr by Cover Type		Total $/year by Cover Type	
Cover Type	***Acres***	***Low***	***High***	***Low***	***High***
Early Forest	964,475	$0	$0	$0	$0
Pole Forest	729,333	$32.20	$445.95	$23,485,000	$325,246,000
Mid Forest	1,374,387	$78.26	$1,093.00	$107,553,000	$1,502,638,000
Late/Old Forest	1,381,127	$395.77	$2,272.00	$546,609,000	$3,137,893,000
Riparian forest pole	215,617	$1,075.20	$11,070.00	$231,831,000	$2,386,900,000
Riparian Forest mid to late	814,628	$3,479.00	$25,226.00	$2,833,749,000	$20,550,050,000
Riparian Shrub	200,180	$0	$0	$0	$0
Fresh Wetland	215,907	$6,676.61	$59,914.27	$1,441,527,000	$12,935,910,000
River/Lakes	121,905	$77.71	$22,013.28	$9,473,000	$2,683,529,000
Shrub/Scrub	594,451	$0	$0	$0	$0
Grassland/herb	320,443	$96.35	$96.35	$30,875,000	$30,875,000
Agriculture	73,266	$29.90	$39.60	$2,191,000	$2,901,000
Pasture	307,242	$6.25	$6.25	$1,920,000	$1,920,000
Urban green space	421,574	$1,293.84	$4,743.10	$545,449,000	$1,999,568,000
Beach	48,341	$22,353.32	$81,528.01	$1,080,582,000	$3,941,146,000
Salt Marsh	83,144	$358.74	$114,739.48	$29,827,000	$9,539,900,000
Eel grass beds	49,422	$5,507.00	$15,421.00	$272,167,000	$762,137,000
Estuary Waters	552,712	$18.62	$1,868.51	$10,291,000	$1,032,748,000
Marine Waters	1,127,891	$259.34	$772.68	$292,507,000	$871,499,000
Totals	**9,596,045**			**$7,460,036,000**	**$61,704,860,000**

The ecosystems which produce flows of economically important services can be seen as a natural capital asset. This analogy can be extended by calculating the present value of the flow of ecosystem services. We refer to natural capital asset value because all natural ecosystems cannot be bought or sold and because, unlike financial capital which grows in paper value over time and can be traded in for real assets, ecosystems are not fungible. We cannot trade one old growth forest to produce an instant old growth forest elsewhere. Thus, calculating net present value is an exercise, it is analogous to the net present value of an asset that can be bought and sold, not identical.

Calculating the present value of an asset in traditional economics requires the use of a discount rate. Discount rates measure the extent to which people value what they can have now, more than putting off consumption or income until later. Current environmental economics literature yields a healthy discussion about whether or not to use discount rates and what rate should be applied to calculate the value ecological assets over time (Azar and Sterner, 1996); there is a variety of alternatives to standard exponential discounting, including using declining rates (Newell and Pizer, 2003) and "intergenerational" discounting which allows the assignment of different, presumably lower, discount rates for future generations versus the current generation (Sumaila and Walter, 2005).

Renewable resources should be treated with lower discount rates than built capital assets because they provide a rate of return over a far longer period of time (potentially thousands of years, or longer, for example, the ozone layer). It would be both unwise and uneconomic to treat our time preference for the ozone layer's protection like we treat a throw away coffee cup.

As discussed earlier, natural capital is different from built capital because, if healthy, it is a self-maintaining asset, unlike built capital which requires active maintenance. This has profound implications for how these are treated across time. Most of the benefits that a natural asset, such as Puget Sound, provides reside in the distant future, whereas most of the benefits of built capital, such as a car reside in the immediate future with no benefits provided in the distant future. Both sets of assets are important to maintain for a high quality of life.

For simplicity, we use the two discount rates, 0 and 3 percent. A zero discount rate implies that we in the present hold future flows of ecosystem services to be just as important to people living in the future as the value of those assets are to us today. We limit the time horizon arbitrarily to 100 years for the zero discount rate. This is short sighted. Without limiting the time period the value of natural assets would be infinite and lose its explanatory function. A 3 percent discount rate implies that people today have a positive time preference so that what remains in the future is less important than what we have today to meet current needs. It is, however, still a lower discount rate than the 5-10 percent range that is typically used to value built capital assets or to calculate expected rates of return on monetary investments.

Calculations of the present value of the flow of ecosystem services do show that intact natural systems provide enormous value to society in the short and long term. We enjoy (require) some of this value now, such as the supply of drinking water, but through time future generations will cumulatively receive very large economic benefits from functioning natural capital. Table 20 shows the present value of the ecosystem services of Puget Sound based on the annual estimate of $7.4 billion for the low estimate and $61.7 billion for the high estimate.

Table 20. Present Value of Ecosystem Service of the Puget Sound Basin

Discount Rate	**Low Estimate**	**High Estimate**
0 % (100 years)	$746 billion	$6 trillion
3 % (100 years)	$243 billion	$2.1 trillion

Limitations of Approach and Results

Appendix B discusses in greater detail the limitations of this approach. The results of this first attempt to assign monetary value to the ecosystems of the Puget Sound Basin are important and significant. Their implications are described below. However, there are limitations to valuation exercises that should be noted. These limitations do not detract from the core finding that ecosystems produce significant economic value to society. Given that we use a very similar approach to the Costanza et al. (2007) valuation of New Jersey's ecosystem services, we draw heavily from their discussion of potential sources of error.

The value transfer methodology, like other meta-studies introduces an unknown level of error; we do not usually know how well the original study site approximates conditions in the policy site (Rosenberger and Stanley, 2006), in this case the Puget Sound Basin, with the exception a few studies conducted in the Pacific Northwest. The following paragraphs show other potential sources of error in this type of analysis[5]:

1. Incomplete coverage is perhaps the most serious issue. Not all ecosystems have been well studied or valued. This results in a serious underestimate of the value of ecosystem services
2. Current price distortions and externalities also tend to result in an underestimate of ecosystem service values.
3. Estimates based on willingness-to-pay depend on people's knowledge base, which is limited concerning ecosystem services.
4. As the sources of ecosystem services become more limited, the valuations likely underestimate shifts in the relevant demand curves. If the Puget Sound Basin's ecosystem services are scarcer than assumed here, their value has been underestimated in this study.
5. Conversely, there is the potential that ecosystems identified in the GIS analysis are fully functioning to the point where they are delivering the values that are assumed in this report. This may result in an over-estimate of current value.
6. The valuation assumes smooth responses to changes. If ecosystems approach thresholds of collapse higher values for affected services would be produced.
7. If a threshold is passed valuation is out of the "normal" sphere of marginal change and larger scale social and ethical considerations dominate, such as an endangered species listing.
8. Bias can be introduced in choosing the valuation studies, as in any appraisal methodology. The use of a range partially mitigates this problem.
9. This method assumes spatial homogeneity of services within ecosystems. That

[5] Several of these limitations were identified in Costanza et al. 1997. Some identified are original to this report.

every acre of forest produces the same ecosystem services. This is clearly not the case. Whether this would increase or decrease valuations depends on the spatial patterns and services involved. Solving this difficulty requires spatial dynamic analysis.

10. This analysis is a static, partial equilibrium framework that ignores interdependencies and dynamics. New models that are dynamic are being developed.
11. The value estimates are not necessarily based on sustainable use levels. Limiting use to sustainable levels would imply higher values.
12. The approach does not fully include the "existence" value of ecosystems.

If these problems and limitations were addressed, the result would most likely be significantly higher values. At this point, however, it is impossible to know how much higher the low and high values would be.

Need for Future Research

The most obvious need for future research is to fill the data gaps in empirical studies on the value of ecosystem services in the Puget Sound region and elsewhere. Published studies are biased towards recreation and aesthetics, water supply, and habitat refugium; nevertheless, coverage is not complete even in these areas. Some of the fundamental ecosystem services upon which life support functions depend, like nutrient cycling and soil formation certainly deserve more attention, as do services that support human health and safety (disturbance regulation, water flow regulation, and biological control). A better understanding of fundamental ecological relationships in the Puget Sound – such as how food web dynamics affect nutrient cycles, disturbance regulation, water quality, and commercial fish populations – is key to ensuring the scientific rigor of assumptions made about the relationships between ecosystem function and ecosystem service delivery. Some of this work is currently being undertaken by the NOAA Pacific Science Center (Guery and Plummer, personal communication). Finally, the static snapshot we produce here, even if it included far more studies of un-covered ecosystem services, would still be lacking because we live in a rapidly changing world.

Dynamic modeling that translates ecosystem change in changes in the delivery and value of ecosystem services would provide a very powerful tool for testing different restoration, land use change, and climate change scenarios. Such models are currently under development by researchers at the University of Vermont and are being applied to the Puget Sound region with local data. The valuation portion of these models is also intended to link to more traditional measures of economic impact that are more tangible than just dollars of non-market benefit. Such measures include the impact of loss of ecosystem services on employment, personal income, and tax revenue. Results from these models are anticipated to be available for the Puget Sound by the end of 2009.

A powerful systems analysis platform called the MIMES Project, will provide far stronger tools for using systems models and physical data to understand how changes, restoration, or damage to ecosystems reap benefits or costs. In addition, a National Science Foundation funded Bayesian ecosystem service analysis (ARIES Project) will enable probabilistic analysis of ecosystem services under conditions of incomplete data.

Conclusion: What These Values Mean for Puget Sound Restoration

The Puget Sound economy and the quality of life for our citizens depends on healthy "natural capital." This report is the most comprehensive valuation of ecosystem services in Puget Sound to date. However, this is only a beginning of analysis. This study should not be taken as the final word on ecosystem service valuation for the Puget Sound Basin but as a first step towards understanding the significant contributions that functioning ecosystems make to the economic well being of the region. **What can clearly be concluded is that even with the incomplete estimates that we present, the value of the annual flow of ecosystem services to residents of the Puget Sound is vast, in the billions of dollars annually. The value of this flow of benefits, analogous to a "capital asset" value of the Puget Sound basin is also vast. The "asset" value of Puget Sound ecosystems is at least on the order of hundreds of billions, and into the trillions of dollars if their value to future residents is counted.** The natural assets of the Puget Sound basin are not immutable. They can and are being lost. This threatens our economy and quality of life.

We have critical investment decisions to make. Confronted with increased flooding, greater numbers of endangered species, larger storm water systems, higher levees, increased taxes for replacing natural systems

This study provides a baseline set of values. What is now needed is a follow-up analysis which examines the returns to restoration and protection investments for Puget Sound. Earth Economics has made these calculations for shoreline restoration and salmon restoration projects, conservation districts, flood districts and other specific applications.

This methodology, and a number of cutting edge tools will enable the rough calculation of the returns on conservation investments. In other regions countries and regions, it has become clear that investing in restoration has high financial returns, for example, Seattle's investment in purchasing the Cedar and portions of the Told River watersheds.

This pioneering report yields preliminary numbers, yet provides unmistakable conclusions:

1. Our quality of life and our economy are dependent upon "natural capital."
2. Puget Sound Basin ecosystems provide economically valuable services, including flood protection, water supply and filtration, food, habitat, waste treatment,

climate regulation, recreation and other benefits. A partial valuation of these services shows a range of economic benefits between $7.4 billion to $61.7 billion/ year.

3. Vegetation types examined here that provide ecosystem services include forests, riparian areas, wetlands, shrub fields, streams, rivers, lakes, farm land, urban forests, wetlands, beaches, eelgrass beds, and open water that is estuarine and marine.
4. The flow of annual benefits from these lands provides a vast amount of value to people across time. The present value of the benefits from these 12 ecosystem goods and services provided by Puget Sound is at least $243 billion to $2.1 trillion. This can be considered as analogous to a capital asset value.
5. There are tremendous gaps in data. Many ecosystem services easily identifiable as economically valuable have no values because no primary valuation study has been completed.
6. This analysis is static more powerful tools for understanding the value of the natural capital in the Puget Sound Basin are being developed. These include systems and Bayesian models.
7. Large scale investments and better land use, to protect and restore the ecological capital and processes of the Puget Sound Basin are clearly justified to maintain and expand the vast value of Puget Sound natural assets.

Given that our entire range of values likely represents an underestimate, our results indicate that restoration and maintenance of Puget Sound's ecosystems is a very prudent investment in the well-being of the region's citizens and businesses. Conversely, if we fail to accomplish restoration and allow further loss of forests, wetlands, and nearshore habitats and continued degradation of fresh and marine water quality, we will lose substantial economic value and a high quality of life in the region.

It is also interesting to note that the value of marketed commodities lies within the range of the value of non-marketed ecosystem services. The true value of these non-marketed ecosystem services is probably higher, thus exceeding the value of market goods from the region's forests, waters, and farmlands. When considering what preserving or restoring these ecosystems might entail in terms of lost value of commodity flows, the value of non-marketed services could very well outcompete traditional commodity values.

Finally, while we may be able to assign values to non-marketed services, it remains challenging to translate these values into income flows for private landowners who manage their lands to maintain or improve the flow of services. This is due to the public, non-excludable nature of many ecosystem services. Developing policy tools that recognize both the negative impacts of ecosystem degradation from private actions on public well-being and the positive impacts of good stewardship would help improve opportunities for restoration on private lands. Such tools could also provide the proper incentives and price signals to limit activities that damage or set back restoration activities.

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Appendix A. List of Value-Transfer Studies Used

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APPENDIX A

Table of land cover type, ecosystem services, valuation study authors, low, high and single values.

Land Cover and Ecosystem Service	Author(s)	Low	High	Single Value
Wetland				
Gas & Climate Regulation	***Subtotals***	***$29.43***	***$267.43***	
	Earth Economics carbon sequestration modeling based on Birdsey 1996	$29.43	$267.43	
Water supply	***Subtotals***	***$199.11***	***$31,404.56***	
	Allen, J. et. al.	$10,488.00	$31,404.56	
	Pate, J. and Loomis, J.			$3,598.28

	Lant, C. L. and Tobin, G.			$199.11
	Lant, C. L. and Tobin, G.			$2,192.67
	Hayes, K. M., Tyrrell, T. J. and Anderson, G.	$1,287.83	$2,001.85	
	Creel, M. and Loomis, J.			$542.65
Water Regulation	***Subtotals***	***$6,357.71***	***$6,357.71***	
	Thibodeau, F. R. and Ostro, B. D.		*$6,357.71*	*$6,357.71*
Refugium Function & Wildlife Conservation	***Subtotals***	***$58.89***	***$12,537.14***	
	Allen, J. et. al.	$5,147.20	$12,537.14	
	Striner and Loomis 1996			$1,479.84
	Knowler, D. J. et. al.	$58.89	$269.91	
Aesthetic & Recreational	***Subtotals***	***$31.47***	***$9,347.33***	
	Allen, J.	$103.35	$9,347.33	
	Whitehead, J. C.	$1,044.66	$2,100.39	
	Thibodeau, F. R. and Ostro, B. D.			$656.33
	Thibodeau, F. R. and Ostro, B. D.	$31.47	$100.68	
	Mahan, B. L., Polasky, S. and Adams, R. M.			$34.75
	Hayes, K. M., Tyrrell, T. J. and Anderson, G.	$1,212.84	$2,318.09	
	Doss, C. R. and Taff, S. J.			$4,626.73
	Doss, C. R. and Taff, S. J.			$4,187.89
	TOTAL	**$6,676.61**	**$59,914.17**	

Forest				
Gas & Climate Regulation: Midseral stand ages	***Subtotals***	***$32.27***	***$623.39***	
	Earth Economics carbon sequestration modeling based on Birdsey 1996	$32.27	$623.39	mid-seral
Gas & Climate Regulation: Late seral stand ages	***Subtotals***	***$43.56***	***$841.50***	
	Earth Economics carbon sequestration modeling based on Birdsey 1996	$43.56	$841.50	late seral
Water Regulation	***Subtotals***	***$9.61***	***$9.61***	
	Loomis, J.B.			$9.61
Pollination	***Subtotals***	***$62.97***	***$282.82***	
	Hougner, C.	$62.97		
Refugium Function & Wildlife Conservation	***Subtotals***	***$269.85***	***$500.24***	
	Kenyon, W. and Nevin, C.			$500.24
	Garber-Yontz et al. 2004	$269.85	$452.57	
Aesthetic & Recreational	***Subtotals***	***$9.78***	***$637.81***	
	Willis, K. G.	$104.04	$190.66	
	Willis, K. G.	$23.78	$40.76	
	Willis, K. G.	$9.78	$17.84	
	Shafer, E. L., et. al.			$538.99
	Maxwell, S.			$11.78
	Bishop, K.			$637.81
	Bishop, K.			$569.01
	Bennett, R., et. al.			$169.13
	TOTAL	**$428.04**	**$2,895.37**	

Rivers and Lakes				
Water Supply	***Subtotals***	***$32.34***	***$843.44***	
	Ribaudo, M. and Epp, D. J.	$843.44	$843.44	
	Piper, S.			$32.34

	Henry, R., Ley, R. and Welle, P.			$429.30
	Croke, K., Fabian, R. and Brenniman, G.			$565.91
	Bouwes, N. W. and Scheider, R.			$617.46
Refugium Function & Wildlife Conservation	***Subtotals***	***$58.89***	***$1479.84***	
	Knowler, D. J. et. al.	$58.89	$269.91	
	Striner and Loomins 1996			$1,479.84
Aesthetic & Recreational	***Subtotals***	***$1.69***	***$19,699.00***	
	Young, C. E. and Shortle, J. S.			$81.85
	Young, C. E. and Shortle, J. S.			$81.85
	Ward, F. A., Roach, B. A. and Henderson, J. E.	$20.48	$1,918.61	
	Shafer, E. L. et. al.			$97.24
	Shafer, E. L. et. al.			$551.74
	Shafer, E. L. et. al.			$1,101.41
	Piper, S.			$240.20
	Patrick, R.,et. al.	$1.69	$25.56	
	Kreutzwiser, R.			$181.25
	Kealy, M. J. and Bishop, R. C.			$12.93
	Cordell, H. K. and Bergstrom, J. C.	$189.67	$796.50	
	Cordell, H. K. and Bergstrom, J. C.	$135.37	$283.79	
	Cordell, H. K. and Bergstrom, J. C.	$283.06	$800.69	
	Cordell, H. K. and Bergstrom, J. C.	$382.24	$1,419.65	
	Burt, O. R. and Brewer, D.			$461.82
	Loomis et al. 2002	$11,131.00	$19,699.00	
	TOTAL	**$92.92**	**$22,022.28**	

Beach				
Disturbance Prevention	***Subtotals***	***$22,213.11***	***$36,006.72***	
	Pompe, J. J. and Rinehart, J. R.		$36,006.72	
	Parsons, G. R. and Powell, M.		$22,213.11	
Aesthetic & Recreational	***Subtotals***	***$140.21***	***$45,521.29***	
	Taylor, L. O. and Smith, V. K.	$418.61		
	Silberman, J., Gerlowski, D. A. and Williams, N. A.		$22,070.44	
	Kline, J. D. and Swallow, S. K.	$35,273.49	$45,521.29	
	Edwards, S. F. and Gable, F. J.		$140.21	
Cultural & Spiritual	***Subtotals***	***$25.12***	***$25.12***	
	Taylor, L. O. and Smith, V. K.		$25.12	
	TOTAL	**$22,238.23**	**$81,553.13**	

Estuary				
Water Supply	***Subtotals***	***$5.90***	***$72.03***	
	Whitehead, J. C., Hoban, T. L. and Clifford, W. B.	$5.90		
	Leggett, C. G. and Bockstael, N. E.		$43.16	
	Bocksteal, N. E., McConnell, K. E. and Strand, I. E.	$72.03		

Refugium Function & Wildlife Conservation	***Subtotals***	***$11.55***	***$1,385.51***
	Johnston, R. J. et. al.		$439.73
	Johnston, R. J. et. al.		$1,385.51
	Johnston, R. J. et. al.		$87.16
	Farber, S. and Costanza, R.		$16.01
	Farber, S. and Costanza, R.		$11.55
	Armstrong, 2003	$22.18	$124.20
Aesthetic & Recreational	***Subtotals***	***$1.17***	***$355.16***
	Whitehead, J. C., Hoban, T. L. and Clifford, W. B.	$1.36	
	Whitehead, J. C., Hoban, T. L. and Clifford, W. B.	$9.22	
	Kahn, J. R. and Buerger, R. B.	$3.71	
	Johnston, R. J. et. al.		$157.42
	Johnston, R. J. et. al.		$308.32
	Johnston, R. J. et. al.		$355.16
	Johnston, R. J. et. al.		$169.12
	Johnston, R. J. et. al.		$234.17
	Morrey, 2001		$1.17
	Morrey, 2001		$72.62
	TOTAL	**$18.62**	**$1,812.70**

Salt Marsh			
Disturbance Prevention	***Subtotals***	***$242.91***	***$95,951.00***
	Costanza et al. in press, Ambio	$242.91	$95,951.00
	Farber, S.		
	Farber, S. and Costanza, R.		
Waste Treatment	***Subtotals***	***$109.78***	***$17,673.84***
	Breaux, A., Farber, S. and Day, J.	$1,340.62	
	Breaux, A., Farber, S. and Day, J.	$109.78	
	Breaux, A., Farber, S. and Day, J.		$17,673.84
Refugium Function & Wildlife Conservation	***Subtotals***	***$1.17***	***$1,017.08***
	Lynne, G. D., Conroy, P. and Prochaska, F. J.		$1.17
	Farber, S. and Costanza, R.		$1.33
	Bell, F. W.	$154.19	
	Batie, S. S. and Wilson, J. R.	$6.26	
Aesthetic & Recreational	***Subtotals***	***$4.88***	***$97.56***
	Farber, S.	$4.88	
	Bergstrom, J. C., et. al.		$14.72
	Anderson, G. D. and Edwards, S. F.	$20.85	
	TOTAL	**$358.74**	**$114,739.48**

Cropland			
Pollination	***Subtotals***	***$2.40***	***$12.10***
	Southwick, E. E. and Southwick, L.	$2.40	
	Robinson, W. S., Nowogrodzki, R. and Morse, R. A.		$12.10
Aesthetic & Recreational	***Subtotals***	***$27.50***	***$27.50***
	Bergstrom, J., Dillman, B. L. and Stoll, J. R.		$27.50
	TOTAL	**$29.90**	**$39.60**

Pasture

Soil Formation	***Subtotals***	***$6.22***	***$6.22***
	Pimentel, D.		$6.22
Aesthetic & Recreational	***Subtotals***	***$0.03***	***$0.03***
	Boxall, P. C.		$0.03
	TOTAL	**$6.25**	**$6.25**

Urban Green Space

Gas & Climate Regulation	***Subtotals***	***$26.81***	***$874.79***
	American Forests		$203.44
	McPherson, E. G., Scott, K. I. and Simpson, J. R.		$26.81
	McPherson, E. G.		$874.79
	McPherson, E. G.		$175.37
Water Regulation	***Subtotals***	***$5.72***	***$170.89***
	American Forests		$170.89
	McPherson, E. G.		$5.72
Aesthetic & Recreational	***Subtotals***	***$1,261.31***	***$3,697.42***
	Tyrvainen, L.		$3,697.42
	Tyrvainen, L.		$1,261.31
	Tyrvainen, L.		$1,862.77
	TOTAL	**$1293.84**	**$4743.10**

Marine

Water Supply	***Subtotals***	***$259.34***	***$772.68***
	Soderqvist, T. and Scharin, H.	$259.34	$431.16
	Nunes, P and Van den Bergh, J.		
	Hanley, N., Bell, D. and Alvarez-Farizo, B.		
	TOTAL	**$259.34**	**$772.68**

Grasslands

Gas & Climate Regulation	***Subtotals***	***$3.85***	***$3.85***
	Costanza et al. 1997	$3.85	$3.85
Water Regulation	***Subtotals***	***$1.65***	***$1.65***
	Costanza et al. 1997	$1.65	$1.65
Soil Erosion Control	***Subtotals***	***$15.97***	***$15.97***
	Costanza et al. 1997	$15.97	$15.97
Soil Formation	***Subtotals***	***$0.54***	***$0.54***
	Costanza et al. 1997	$0.54	$0.54
Waste Treatment	***Subtotals***	***$47.91***	***$47.91***
	Pimentel et al. 1995	$47.91	$47.91
Pollination	***Subtotals***	***$13.77***	***$13.77***
	Pimentel et al. 1995	$13.77	$13.77
Biological Control	***Subtotals***	***$12.66***	***$12.66***
	Pimentel et al. 1995	$12.66	$12.66
	TOTAL	**$96.35**	**$96.35**

Eel Grass Beds

Nutrient Cycling	***Subtotals***	***$5,507.00***	***$15,421.00***
	Costanza et al. 1997	$5,507.00	$15,421.00
	TOTAL	**$5,507.00**	**$15,421.00**

Appendix B Limitations of Approach and Results

The limitations of benefit transfer methodologies have been well discussed in the literature. These limitations do not detract from the core finding that ecosystems produce significant economic value to society. Given that we use a very similar approach to the Costanza et al. (2007) valuation of New Jersey's ecosystem services, we draw heavily from their discussion of potential sources of error.

The value transfer methodology introduces an unknown level of error; we do not usually know how well the original study site approximates conditions in the policy site (Rosenberger and Stanley, 2006), in this case the Puget Sound Basin, with the exception a few studies conducted in the Pacific Northwest. The following paragraphs show other potential sources of error in this type of analysis[6]:

1. Incomplete coverage is perhaps the most serious issue. Not all ecosystems have been well studied and, as evidenced by Table 8 above, some have not been studied at all. More complete coverage would almost certainly increase the values shown in this report, since no known valuation studies have reported estimated values of less than zero.
2. Distortions in current prices used to estimate ecosystem service values are carried through the analysis. These prices do not reflect environmental externalities, they are likely to be underestimates of "true" values.
3. Most estimates are based on current willingness-to-pay or on proxies which are limited by people's perceptions and knowledge base. Improving people's knowledge base about the contributions of ecosystem services to their welfare would almost certainly increase the values based on willingness-to-pay; people would realize that ecosystems provide more services than they had previously known.
4. As the sources of ecosystem services become more limited, the valuations likely underestimate shifts in the relevant demand curves. If the Puget Sound Basin's ecosystem services are scarcer than assumed here, their value has been underestimated in this study. Such reductions in "supply" appear likely as land conversion and development proceed. Climate change is also likely to adversely affect the Puget Sound's ecosystems, putting more stress on the resilience of these systems and their continued ability to deliver services.
5. Conversely, there is the potential that ecosystems identified in the GIS analysis are fully functioning to the point where they are delivering the values that are assumed in this report. This may result in an over-estimate of current value.
6. The valuations assume smooth responses to changes in ecosystem quantity with

[6] Several of these limitations were identified in Costanza et al. 1997. A few are original to this report.

no thresholds or discontinuities. Assuming (as seems likely) that such gaps or jumps in the demand curve would move demand to higher levels than a smooth curve, the presence of thresholds or discontinuities would likely produce higher values for affected services (Limburg et al., 2002).

7. The issue identified above in item 6 could also imply that an ecosystem could suddenly pass a threshold where it can no longer provide a service. Such a change moves valuation out of the "normal" sphere of marginal welfare economic analysis into social and political decision-making where price is less important than larger scale social welfare losses and ethical considerations (Swedeen, 2004).
8. As noted above, the method used here assumes spatial homogeneity of services within ecosystems. The spatial modeling component of the New Jersey analysis (Costanza et al. 2007) was intended to address this issue and showed that, indeed, the physical quantities of some services vary significantly with spatial patterns of land use and land cover. Whether this fact would increase or decrease valuations is unclear and depends on the specific spatial patterns and services involved. Conducting a spatial dynamic analysis for the Puget Sound Basin would increase the scientific rigor of value estimates (further discussed below).
9. Our analysis uses a static, partial equilibrium framework that ignores interdependencies and dynamics. More elaborate systems dynamics studies of ecosystem services have shown that including interdependencies and dynamics leads to significantly higher values (Boumans et al., 2002), as changes in ecosystem service levels ripple throughout the economy. Efforts are underway to conduct a more sophisticated set of analyses with dynamic changes in ecosystems taken into account and linked to input-output models to show direct implications to the economy. The Puget Sound is a case study for these efforts (The Gund Institute, 2007).
10. The value estimates are not necessarily based on sustainable use levels. Limiting use to sustainable levels would imply higher values for ecosystem services as the effective supply of such services is reduced.
11. The approach does not fully include the "infrastructure" or "existence" value of ecosystems. It is well known that people value the "existence" of certain ecosystems, even if they never plan to use or benefit from them in any direct way. But estimates of existence value are rare. Including this service would obviously increase the total values.
12. On a global level, making inter-country comparisons presents great difficulties and imprecision. Since majority of value transfer estimates were from the US or other developed countries, this problem was of limited relevance to the current project.
13. In the few cases where we needed to convert from stock values to annual flow values, the amortization procedure also creates significant uncertainty, both as to the method chosen and the specific amortization rate used. (In this context, amortization is the converse of discounting.)

14. All of these valuation methods use static snapshots of ecosystems with no dynamic interactions. The effect of this omission on valuations is difficult to assess, but efforts are underway to address these uncertainties.
15. Because the transferred value method is based on average rather than marginal cost, it cannot provide estimates consumer surplus. However, this means that valuations based on averages are more likely to underestimate total value.

If these problems and limitations were addressed, the result would most likely be significantly higher values. At this point, however, it is impossible to know how much higher the values would be.

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