2015 LRES Capstone Papers

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The fall 2015 LRES Capstone Class focused on clearly defining the terms Ecosystem Functions and Ecosystem Services. These terms are often confused in the literature and in application. As a part of defining the terms, the Capstone students researched management or restoration case studies where these concepts are applied in concurrence or in contradiction. In the middle of semester, the Executive Office of the President released a memorandum directing all government agencies to "develop and institutionalize polices to promote consideration of ecosystem services, where appropriate and practicable, in planning, investments, and regulatory contexts." That memorandum directs agencies to develop a framework to identify and classify key ecosystem services and to assess impacts to those services from Federal actions. Part of that framework will require a clear distinction between ecosystem functions and ecosystems services. With this memo, the LRES Capstone Class suddenly found themselves as the vanguard of applied thought in resource management.

The Class prepared three separate group projects to address how these definitions are applied to 1) agriculture systems, 2) aquatic ecology, and 3) water quality. Below are those papers.

The Role of Ecosystem Functions and Ecosystem Services in a Growing Human Population

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Introduction

Despite the relatively short existence of humans on Earth, man has had a powerful impact on the planet. During the second half of the twentieth century, the human population increased significantly and with it, the number of mouths to feed (Stoop, 2001). The concern is how to sustain this population increase in a continuously degraded environment as soil health declines and agricultural keystone species disappear. Within the past few decades there has been a major push for ecosystem remediation – especially remediating the functions of ecosystems that have been altered by human activity. Functions are synonymous with the innate processes of the ecosystem (Gómez-Baggethun, 2010). Ecosystem services are products of ecosystem functions that sustain, support, and promote the wellbeing of people (Figure 1; Galatowitsch S, 2012). When ecosystem functions are impaired, ecosystem services are also impaired. Loss of these vital services is incredibly detrimental to a world desperately trying to sustain a growing human population.

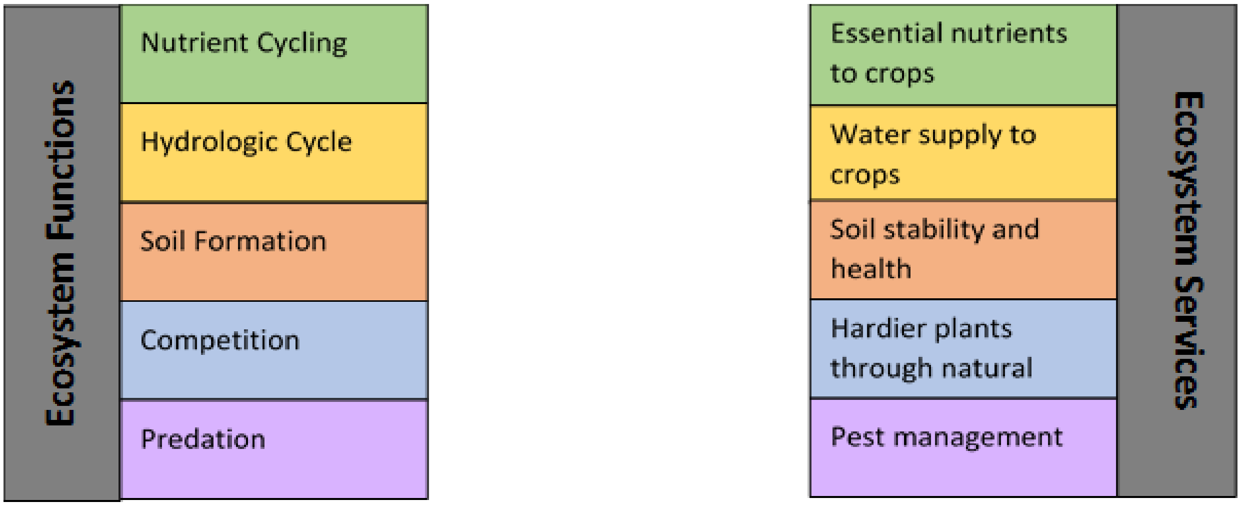


Figure 1. Ecosystem functions are the processes of an ecosystem. Ecosystem services are the beneficial products to human from ecosystem functions.

Luckily, this need for preserving the integrity of ecosystem functions and the resulting services has not gone unnoticed. On October 7, 2015, the White House issued a new memorandum directing Federal agencies to incorporate the value of ecosystem services into Federal planning and decision-making. The economic services and social well-being that natural ecosystems provide are frequently not traded in markets or considered in decision making. The health of ecosystem functions and ecosystem services is essential for the existence of a sustainable world. This paper discusses the importance of recognizing ecosystem functions and the resulting services, in particular to sustaining a growing human population.

Ecosystem Functions and Services

Ecosystem Services

Contemporary history of the term "ecosystem services" began in the 1970's and 80's with the hope of raising public interest in biodiversity conservation as well as to emphasize the public's dependence on natural systems (Ehrlich & Ehlich,1981; Gómez-Baggethun E., 2010; Westman, 1977). Traditionally in the field of ecology, the term "ecosystem function" is defined as the natural processes within an ecosystem apart from any additional benefit to humans (Gomez-Baggethun, 2010). By expressing contemporary ecological concern in an economic manner, authors were able to stress how potential loss of biodiversity would create a cascading effect on ecosystem functions and the associated beneficial loss of services provided to humans. By the 1990's, the study of ecosystem services became common in research (Gomez-Baggethun, 2010). Near the early 2000's, concepts of ecosystem services began to appear in politics and policy leading to advancements in controls on emissions as well as application with the existing Clean Air Act and Clean Water Act (Gomez-Baggethun, 2010). More recently, design of market based tools are used to produce economic incentives for conservation. These tools approximate an economic value for services, which are then incorporated into economic decision making, and thus provide a mechanism for trading such services (Gomez-Baggethun, 2010). This shift in thinking and policy-making stressed the importance of ecosystem services to the anthropogenic world.

Ecosystem services are becoming an increasingly studied facet of ecological and human interactions, and as such, are becoming more heavily weighted as contributing factors to the world economy and its markets (Gomez-Baggethun, 2010). Within the past thirty years, sustainable science and the practices involved therein have instilled a concern for societal dependence on natural ecosystems, creating incentives for the conservation of ecosystem services (Gomez-Baggethun, 2010). This societal dependence becomes apparent when discussing any natural or agricultural resource, such as timber, coal, or (as is highlighted here) food.

Ecosystem Functions

To understand the decline of ecosystem services, it is best to view them in light of the ecosystem function from which they are derived. In agriculture, starting with below ground activity, the formation of soils create stability and support for root structure (an ecosystem function), providing the foundation for crop growth aboveground (an ecosystem service). Precipitation transports water to the surface of the earth (an ecosystem function) where infiltration of water into the soils (an ecosystem function) provides crops with needed water (an ecosystem service). Several functions can be intentionally exploited to acquire specific agricultural services. For example, farmers can facilitate nutrient supply to crops by providing favorable conditions for soil microfauna. Soil organisms increase the chance of productive nutrient cycling by degrading organic matter into smaller components. Organisms at lower trophic levels are then able to utilize this degraded material. Eventually, the nutrients from the original organic matter is returned to the soil as these organisms die and decompose, or as they are preyed upon by other species, which then input the nutrients to the soil through excrements (Matson et al, 1997). Essentially, ecosystem functions drive all ecosystem services.

Degradation of Ecosystem Functions

Focusing exclusively on nature's ecosystem services and the benefits they provide is anthropocentric, especially when the focus results in enhancing the ecosystems to provide only a few services that are important to a particular industry. All ecosystems, even heavily impacted ecosystems, perform functions. However, over time, systems continuously exposed to stress become simplified through disturbance resulting in the elimination of many functions (Altieri, 1999). Not considering the potential threats humans pose on ecosystems can result in degradation of important ecosystem functions as well as the coupled services. Several economic and ecological trade-offs take place in the agro-ecological network. For instance, an increase in crop yield leads to an increase in profit by farmers, which enhances the agricultural economy. Yet, crop farmers typically reduce biodiversity of an ecosystem through conversion of non-agricultural land to cropland, eliminating many ecosystem functions in the process. The lack of biodiversity in high-input farming systems contributes to the degradation of natural pest management, disease resistance, and soil formation. (Altieri, 1999) The fixation of nitrogen, an essential nutrient for all crop species, relies heavily on the diverse array of microorganisms in the soil (Matson et al, 1997). A soil system degraded from intensive agriculture use loses its ability to cycle nutrients and as a result the beneficial ecosystem service of nitrogen fixation previously supplied to the human population free of charge declines. This service must now be replaced with artificial supplies of nitrogen. While fertilizer application is an efficient way to increase short-term crop yields, enhancing the system with chemicals leads to increased costs that are added into the product as well as concern with associated runoff, and depletion of limited resources such as phosphorous.

Across the world, a number of ecosystem functions have been degraded from human activity resulting in inefficient and insufficient food supply for an exponentially growing populous. World population has grown to over 7 billion people (US World Consensus 2012) and has resulted in an increasing demand for food over the last century. This increasing demand calls for more efficient crop yields, which are generally obtained through the use of agricultural practices involving increased use in pesticides, fertilizers, and technology (Bretagnolle, 2015). Intensification of agricultural land use has a direct effect on the soil and the biodiversity of an ecosystem (Bretagnolle, 2015), in turn affecting a broader range of ecosystem functions.

Soil Functions

Management of soils for sustainable use on a global scale is considered to be one of the greatest challenges for the 21st century (Morel, 2014). Natural soils provide many beneficial functions. One such function is the role soil plays in supporting plant growth. Healthy soils are essential in plant establishment. After that, turnover and decomposition of biomass results in the accumulation of organic matter which further supports vegetation. Specifically, the presence of soil organic matter (SOM) affects the composition and health of soil biota. Most soil microorganisms are saprophytes, which depend on SOM and litter fall as a source of energy (Gurevitch, 2002). In return, these organisms decompose detritus, and thus cycle nutrients, making them available to plants growing in the soil. SOM affects the plant community composition that establishes by increasing the availability of seeds or propagules (plant material used for the purpose of plant propagation) that stick to the substrate, subsequently increasing the likelihood of plants to colonize. SOM also increases water-holding capacity of the soil, which is important for establishment of shallow rooted plants as well as some microorganisms that require water for movement. In addition, SOM increases cation exchange capacity, the availability for cations to be adsorbed, which helps in increasing nutrient concentrations and reducing the loss of nutrients to leaching. Increased cation exchange capacity also provides a buffer against soil acidification (Gurevitch J, 2002). Furthermore, SOM provides a less compact, more aerated environment that is more supportive of plant communities.

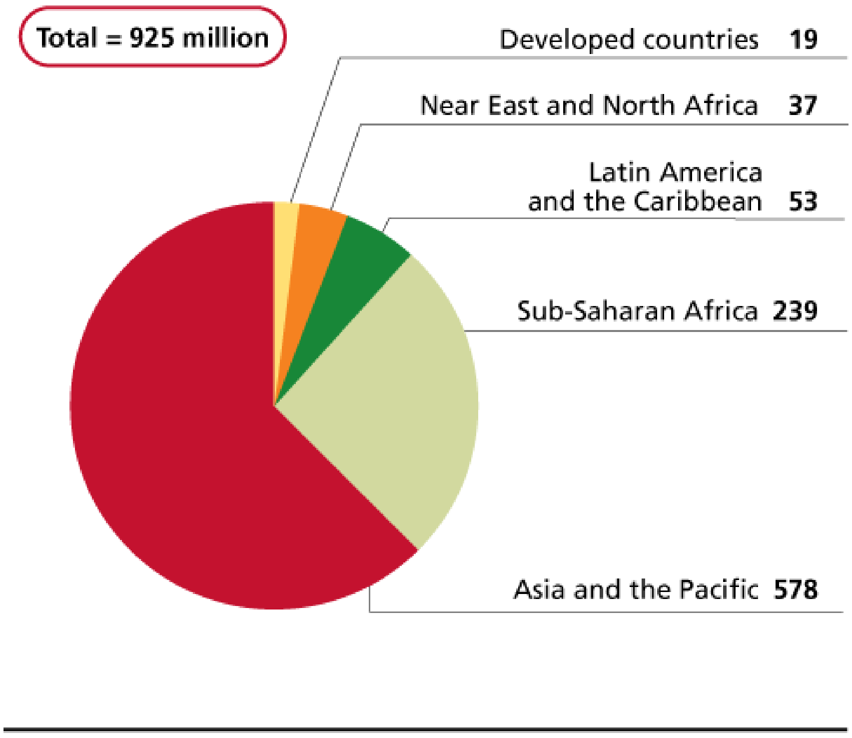
In comparison, a degraded soil is characterized by low soil fertility, SOM, organic carbon content and loss in biodiversity, water holding capacity, the disruption of water, nutrient, and gas cycles and a reduced capacity to degrade contaminants (Morel, 2014). Consequently, a degraded soil system reduces its ability to function normally, resulting in the alteration of beneficial ecosystem services previously provided to humans. Such soil degradation can occur during the agricultural production of large monoculture crops.

Ecosystem Functions and Biodiversity in Monoculture Crops

Disturbance imposed by agricultural practices typically alters the community composition of an ecosystem. In agriculture, a diverse community can contribute to producing higher crop yield and nutrient rich soil. On the contrary, agricultural development of large monoculture croplands can have detrimental effects on biodiversity with consistent annual crop production, spraying of non-crop plants, harvesting above ground biomass (crop), and tillage practices. These four practices of monoculture farms have detrimental effects on plant biodiversity and in result have greatly impacted the honey bee; a crucial pollinator for many common crops today, including coffee, cacao, and a wide array of fruits and vegetables (Bretagnolle, 2015). Soil pollution is another cause of decreased biodiversity - toxins decrease the number of plants that can establish in soil. When toxins are in low concentration the biodiversity of microbial and plant life increases, and the ecosystem can properly perform functions like nutrient cycling and carbon storage.

Agriculture Industry

Beginning in the 1960s, agricultural research greatly expanded, leading to a time known as the Green Revolution. Yet, years of research rooted in modern technologies have failed to find a solution to the world food problem. An intensification of agricultural land output focused on producing higher densities of crop yield per unit surface area. Farming techniques moved towards mechanization to decrease labor costs, large external inputs such as pesticides and fertilizers were applied to control pests and boost crop growth, and larger irrigation systems were installed to supply these crops with an adequate water supply (Stoop *et al*. 2001). As of 1999, twelve species of grain crops, twenty-three vegetable crop species and thirty-five fruit and non-crop species were cultivated across the entire globe (Altieri, 1999). With little variation in crop diversity and high reliance on inputs (fertilizers, seeds, pesticides) continuously provided by anthropogenic influence, agriculture systems can be precisely modeled and predicted (Rodenhouse, 1992). While this system may be manageable for large scale farming systems, a large part of the world never sees this food and it is this fraction of the population that needs food the most (Altieri, 1999). As of 2015, the estimated number of hungry in the world reached 925 million (ECHO, 2015). The majority of these hungry people are located in Sub-Saharan Africa, Asia, and the Pacific (Figure 2; ECHO 2015). These communities rely directly on the crops they produce to feed their families and communities because access to food is otherwise impossible due to lack of finances or accessibility (Chambers *et al*. 1985). The Resource Poor Farmers (RPF) in these communities do not have access to the high inputs and modern machinery that high yielding agriculture systems rely on. For the RPF, degraded ecosystem functions eliminate the ecosystem services that provide the means to sustain crop production and therefore the farmer's livelihood. The problem with the shift experienced during the Green Revolution is that researchers and farmers alike have confounded ecosystem functions and ecosystem services. While this drastically affects the RPF, all farming systems experience a loss of ecosystem functions altering the services they can provide. The shift in agricultural research, therefore, should be moved away from large-scale, high input systems (systems that receive high levels of



Source: FAO.

Figure 2. Number of hungry in the world by 2015 estimates. The majority of the hungry occur in Sun-Saharan Africa, Asia, and the Pacific. Many of these communities do not have access to high input farming methods (ECHO 2015).

fertilizers, herbicides or any other input), to understanding the processes that the environment can provide to farmers in resource poor areas. Not only will ecosystem functions and services then be considered, but food production in hungry regions of the world could see increase in crop yields. The loss of plant diversity, addition of chemical inputs, and overall destabilization of ecosystem functions goes beyond affecting the resource poor farmer.

The Importance of the Honey Bee

Honey bees have a direct influence on the human populace as their activity provides an extremely important ecosystem service – pollination of the global food supply. Approximately 35% of global major crops such as coffee, cacao, and a wide array of fruits and vegetables depend on pollination performed by domesticated bees (Bretagnolle, 2015). It is also estimated that without the presence of pollinators, world crop production would experience a decline of 3-8% (Bretagnolle, 2015).

Providing arguably one of the most important functions in agricultural systems, the European honey bee has been hit hard. Within the last twenty years, the rise of multifaceted problems in honey bee populations such as Colony Collapse Disorder (CCD) has contributed to the realization that the planet is suffering from several environmental stress factors; influencing bees and their ecosystem services. Colony collapse disorder was first recognized as a honey bee pathogen during the winters of 2007 and 2008. This phenomenon is generally defined by an absence of adult bees within a colony, the presence of capped brood (bee larvae which have been left sealed inside the honeycomb), few or no dead bees within a collapsed hive, and the presence of undisturbed food stores (Ellis,2010). Weakened colonies may also exhibit an insufficient number of worker bees, the populations of which are generally dominated by much younger bees than the workforce of a typical healthy colony (Ellis, 2010). Although the exact cause of CCD has yet to be discovered, several hypotheses have since been formulated based on research of other pathogens resulting in colony loss. These include traditional bee pathogens and pests, management stress, poor genetic biodiversity, pesticide use, toxins present in the environment, bee nutritional deficits, and undiscovered pathogens increasing virulence of existing pathogens (Ellis, 2010). A common factor in the worldwide decline of bee populations is that of human influence. The above hypothetical causes of CCD may all be influenced by heavy input agricultural practices involving domesticated bees, which in turn affect the ecosystem functions and services bees provide.

Honey Bee Functions

Demand for food to support the growing world population over the last century has substantially increased. This demand ultimately leads to the alteration of natural systems and the development of agricultural landscapes and the use of high input management practices. In the end, this contributes to the decline of honey bee functions, which can be seen in the following example.

A natural system includes a diverse plant community which corresponds to the system’s landscape diversity. This plant community usually includes several different plant populations which will flower at different times throughout the year, creating a landscape function which naturally supports native pollinators in the system by providing a constant source of food. However, high input agriculture generally results in decreased biodiversity of plant families through regulation and elimination of undesirable flora (weeds) in an area dedicated to crop production.

For example, an area which is now farmland could have once been a wetland or forested area, each with its own natural features and ecosystem functions. Altogether, agricultural intensification has resulted in a decrease in native and non-native plant diversity of approximately 50% in the last 70 years (Bretagnolle, 2015). Abundance of undesirable plants reduces crop yields; therefore giving farmers incentive to incorporate the use of herbicide sprays in their agricultural operations (Bretagnolle, 2015). This practice, while pivotal in the success of most high input agricultural operations, ultimately results in decreased biodiversity throughout agro-ecosystems. Although this may seem beneficial to global agriculture, plant biodiversity ensures that honey bees survive in the absence of crops. Plant communities adjacent to farmland provide a constant, more reliable source of pollination and diet than one crop planted on an annual cycle (Bretagnolle, 2015). When crops are out of season, bees forage on nearby plant species in order to sustain the colony year round (Figure 3). The absence of a diverse plant community causes considerable gaps in times of flowering throughout an agro-ecosystem, which decreases the availability pollinator food sources at various points throughout the year (Bretagnolle 2015). The loss of this resource has a negative effect on the pollinators in the area, which no doubt hinders the bees’ ability to efficiently perform pollination of the crops in the system. As can be seen, the function of a diverse plant community can influence the honey bee driven service of crop pollination, ultimately affecting crop yield in the system. However, biodiversity is not the only factor affecting global crop yield in agricultural ecosystems.

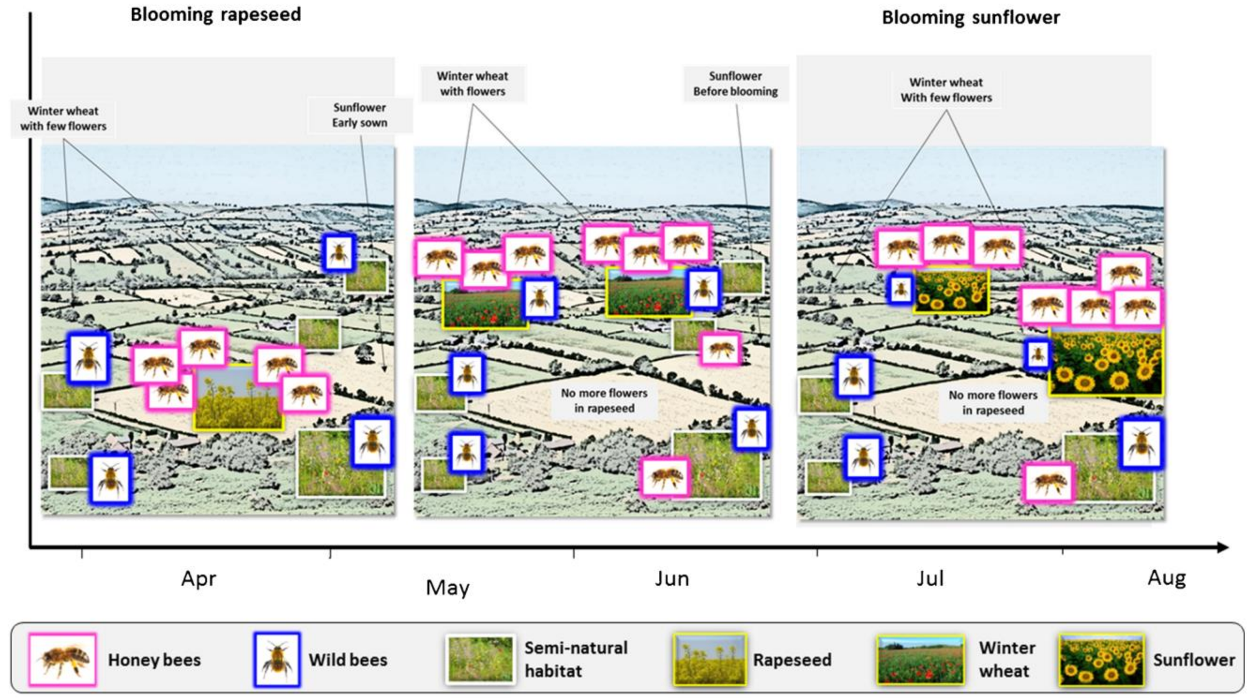


Figure 3. From Bretagnolle 2015. Seasonal foraging patterns for wild and domesticated honey bees. The first panel illustrates bees foraging on blooming rapeseed in April. As summer progresses, the bees move to foraging on nearby winter wheat fields as seen in panel two. Panel three shows the same bee populations now foraging on blooming sunflowers in late summer.

Remediating Degraded Soils to Restore Function

Soil pollution directly impacts agriculture by lowering crop yield. Pollutants are commonly heavy metals leached from industrial runoff, mining, and groundwater. Contamination of soil and water resources by heavy metals not only affects the ability of a soil to function at its normal state, but can also threaten food availability, water safety, and human health. Heavy metals are toxic when consumed, making the land no longer suitable for food production. Numerous methods have been constructed for handling soil pollution. The most cost effective and popular method for removal of heavy metals from the soil is phytoremediation.

Phytoremediation is defined as the use of plants for containment, degradation, or extraction of xenobiotics from water or soil substrates" (Bahareh et al., 2012). Phytoremediation restores natural soil functions by increasing microbial biomass as well as natural nutrient cycling, in turn influencing higher plant density and biodiversity aboveground. This aids in supporting a more natural and productive system. Cleaning up farmland via phytoremediation can assist in returning degraded land back into highly valued production (Lewandowski, 2005). Two types of crops can be used in the process of phytoremediation: hyperaccumulators (crops that can tolerate high metal concentrations in their biomass), and crops with greater aboveground yield and lower concentrations of heavy metals (Lewandowski, 2005). After growth of metal contaminated biomass has been accomplished, crops are harvested and various methods (including combustion) are used to extract and contain metals. The biomass grown also acts as stabilization of contaminated soils and later can be used as a source of renewable energy (Lewandowski, 2005). However, some plants can transform the toxin or metal they uptake.

Phytoremediation with Edible Plants

One novel approach to phytoremediation is using edible plants and fungi as a means to accumulate and transform toxins. The edible plants or fungi performing the remedy can then be harvested and used for animal feed and potentially human consumption, supplying ecosystem services from restoring soil function. For instance, oyster mushrooms were found to uptake and transform olive oil mill wastewater (OMWW), making them potentially edible. OMWW is unable to be broken down by microbes and chemicals because of its high abundance of polyphenols (Laconi et al., 2007). One case study by Laconi and colleagues (2007) examines the use of edible plants to restore ecosystem functions impacted by olive oil wastewater (OMWW) and the potential ecosystem services that this approach provides. This case study will examine the use of edible oyster mushrooms to uptake and transform olive oil wastewater (OMWW) that were otherwise unable to be broken down by microbes and chemicals because of its high abundance of polyphenols (Laconi, 2007). TCE, also known as trichloroethylene, is another toxin from industry commonly found in ecosystem. It is speculated to be a carcinogen for humans and cytotoxic to the liver (Schnabel, 1997), but edible garden plants were found to uptake and transform TCE, in another case study. Olive oil wastewater and TCE are two examples of toxins that lower the ecosystem service of agricultural yield through soil degradation.

Case Studies

Olive oil wastewater is the byproduct of olive oil production. Its high abundance of polyphenols and acidity kill a large density of vegetation. Olive oil mill wastewater is acidic, contains many phenols (Zervakis, 1996), and has antibacterial properties that kill microbes present in the soil. This wastewater is typically dumped into nearby rivers or soil, killing a vast amount of vegetation (Laconi et al., 2007). Laconi and colleagues (2007) tested the effectiveness of using oyster mushrooms, *Pleurotus* genus, on land polluted with olive oil mill wastewater in Italy. They found that the complexity of compounds in OMWW made growth impossible on untreated samples of OMWW by attempting to grow microbial and fungal biomass on a sample of pure wastewater. The most effective way to incorporate fungal bioremediation was to alter OMWW's chemical structure with oxidation by addition of $Ca(OH)_2$ or H_2O_2, a simple procedure. After the solution was altered, strains of various fungi and microbes easily grew and reached highest colony forming units at about 2 weeks, with oyster mushrooms in the highest density (Figure 4).

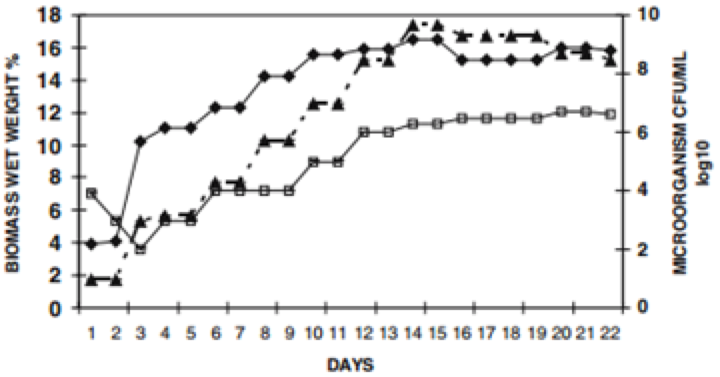


Figure 3. The amount of Microbes and Total Biomass found after 22 days of growth on altered OMWW solution infused agar. Diamonds are total biomass. Triangles are fungal biomass. White squares are bacteria biomass. (Laconi et al, 2007).

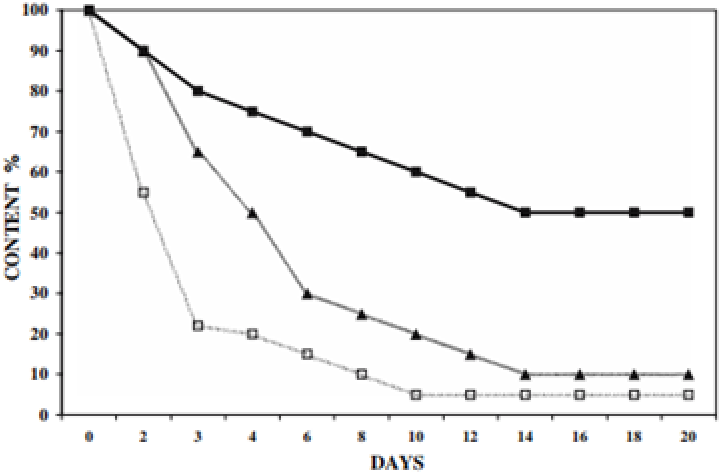
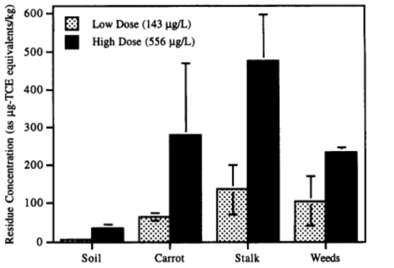


Figure 4. The amount of polyphenols, sugars, and proteins found in agar after 22 days of growth. White squares are sugars, triangles are polyphenols, and the squares represent proteins. (Laconi et al, 2007).

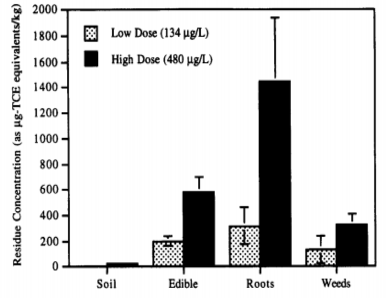
Of the total microbial biomass found in the agar plates containing OMWW, 60% was Pleurotus species. Oyster mushroom growth over a period of 20 days decreased the amount of polyphenols present in the OMWW to 10% in the agar plates. This means that 90% of the polyphenols in the OMWW were consumed. These mushrooms reached all the legal requirements for edible species except for the amount of organics, carbon molecules, present. These were a little higher than the legal limit for human consumption, a result of OMWW transformation. There is a potential for the oyster mushroom product to be used as animal feed for animals with complex digestive systems. Beginning in 1996, the oyster mushrooms from OMWW phytoremediation started to be a food source for cows and other ruminants (Zervakis 1996). Using oyster mushrooms aids soils in performing functions like nutrient cycling and supporting plant life from the removal of toxins because toxins alter the microbial biomass and soil structure, thus effecting the plant biomass. Oyster mushrooms from phytoremediation can provide the service of food supply to the meat and dairy industry as well as a sustainable approach to grazing by reduction of feeding on grasses.

Trichloroethylene is unfortunately abundant and toxic in many soils throughout the world. It is the number one pollutant in our water table from solvents, fertilizers, and industrial byproducts (Schnabel et al., 1997). TCE is a halocarbon that can denature and kill enzymes in plants and animals, lowering the amount of plant growth for a given ecosystem where it is in high concentrations (Fuller, 1997). Schnabel and collaborators (1997) tried to determine the fate of TCE in edible plants in order to assess health and the risk of TCE presence in the environment. It was observed that the plant species were transforming the radiolabeled TCE into non-toxic organics. The plants were exposed to both high doses and low doses of TCE. An edible fruit, root, and leaf were observed using tomato, carrot, and spinach, respectively. In high and low concentrations of TCE, all three of the plants were able to uptake the molecule and transform it. The plants performed higher TCE uptake and transformation with higher exposure of the toxin (Figure 6).

Carrot TCE Concentrations



Spinach TCE Concentrations



Tomato TCE Concentrations

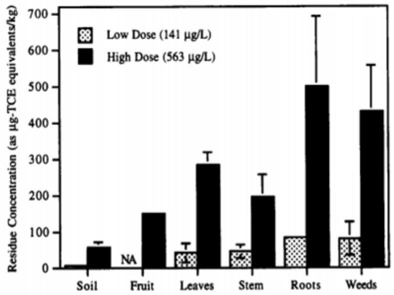


Figure 5. Concentration of high and low dose TCE and the amount of uptake by various parts of the carrot, spinach, and tomato. (Schnabel et al, 1996).

TCE accumulated in different parts of the plants and transformation was observed by lower concentrations of the toxin in the edible tissue of each plant. When the plants were only exposed to a low dose of TCE, not as much uptake was observed. The radiolabeled carbon in all three of these plants indicated that the edible portion of this plant tissue did not contain a high concentration of detectable TCE. If the plants were not able to transform the TCE, there would be concentrations similar to the dosages of the TCE solutions in the plant tissue. There was only about 1-2% of TCE related radiolabels found in the plant tissue of all three specimens. Yet, TCE could be covalently bonded to plant tissue, making it very hard to detect. Further studies need to be done to determine the nutritional value and potential threats of eating these plants, but Schnabel believes that the TCE has been transformed so greatly that there could be little to no risk ingesting these plants. These plants can be used for ruminant consumption, providing an economical and environmental way to provide food to the meat and dairy industry while restoring soil function. Similar to removal of OMWW from a degraded environment, removal of TCE from a polluted soil will create a less toxic environment for microbes and plants to establish which increase the nutrient cycling and stability of the soil.

In conclusion

In industrial agriculture systems, the cascading effects of degrading soil, biodiversity, and phenological functions also diminish the ecosystem service of crop production. Recognizing soil functions is the most effective way to discover issues with ecosystem health and have a better understanding of the services provided by a healthy soil. Simply by incorporating buffers of native vegetation, large agriculture could restore a modicum of natural soil structure and the native soil fauna. Without such buffers, soil is less stable and thus its capability to provide a sufficient crop yield is lowered. Lack of native vegetation also negatively affects pollinators, like the European honey bee, a species crucial for the agricultural industry. Countries that have the money and equipment to have large scale agriculture industries can absorb the degraded functions of soil by manipulating the ecosystem, but in areas of the world where food is needed, farmers are considered resource poor because they cannot use these large scale practices. Yet, if the resource poor farmer looked at his or her ecosystem with a function-based eye, they would understand what the system needs to provide services, like crop production. Resource poor farmers and agriculture industries could also use edible plants to help restore degraded sites back to a healthy state by reintroducing fauna, removing toxins, and providing better soil structure. In highly degraded sites, poor in biota composition and rich in toxins, phytoremediation with edible plants may be that the most productive way of creating a healthy ecosystem while producing vital ecosystem services. Findings within the discussed case studies have supported that edible plants and fungi are capable of toxin uptake and transformation. Toxin uptake will ultimately help sustain plant life for sensitive species and in turn provide benefits to the resource poor farmer and the European Honey Bee. Thus, edible plants could provide a groundbreaking method for agriculture and restoration. Arguably the most coveted ecosystem service, food production, could be managed to benefit this hunger-stricken world and preserve ecosystems.

Improving Aquatic and Riparian Ecosystems for Increased Services

Will Allen, Abby Cutting-Smith, Nikki Huertas, Sam Tittle

Introduction

A healthy aquatic system consists of functions that are often important for both humans and wildlife. Ecosystem functions are the abiotic and biotic processes that happen in nature. Ecosystem services characterize the benefits humans acquire, directly or indirectly, from ecosystem functions, however, these services rely on ecosystem functions operating properly. Historically, ecosystem services have not always been taken into consideration in the decision making process when determining changes in land use and management. A memorandum released on October 7, 2015 from the Office of the President of the United States asks agencies to define ecosystem services and incorporate the definitions into future planning, management, and regulatory decisions. Currently, ecosystem services are frequently conflated with ecosystem functions creating confusion in scientific literature and in applied management settings (White House, 2015). This executive memorandum will help to clarify the definition of ecosystem services and provide a sturdy foundation for management efforts.

The purpose of this paper is to further clarify the differences between function and services. This will be accomplished by looking at the issue with valuing services and looking the functions and services of aquatic and riparian ecosystems. The case studies presented here show that restoration of riparian wetlands and stream systems improve ecosystem services. The three ecosystem functions water storage, wildlife habitat, and productive fisheries are looked over in three separate case studies by looking at wetlands enhanced by beavers, the reintroduction of wolves to Yellowstone, and restoring a salt marsh.

Valuing Services

Value is a measure of worth and is ultimately a product of human perception. This subjectivity can make quantifying and qualifying the value of an aquatic system can be difficult. It must be understood that an ecosystem services supplies a public need and its value is defined by humans. Unless a landscape scale is used, less valuable ecosystems may be converted to ecosystems that generate large revenue. For instance, wetlands have not always been valued and were often drained for “more valuable” purposes, such as agriculture, which generates billions of dollars per year and provides food for a growing population (Costanza et al., 1997). This billion dollar industry is a short term and obvious gain while value of lost aquatic and riparian ecosystems services can be hard to calculate (Mitsch and Gosselink, 2000). Approximately 70% of riparian wetlands in the United States were lost between 1940 and 1980 before the government passed various acts to protect them (Dodds and Whiles, 2010). The new memorandum further helps protect and restore these important ecosystems.

Restoration of wetlands can be an important first step in improving aquatic and riparian ecosystems, which in turn benefits humans. Restoring wetlands can have a positive effect on aquatic and riparian ecosystems by providing habitat for wildlife and fisheries, generating billions of dollars annually. Management strategies that take into account the ecological principles that underlie the comprehension of how and how well wetlands function are needed to protect these functions (Sheldon *et. al,* 2005). These principles focus on spatial and temporal scales, species roles, composition, abundance, and interactions. Looking at the landscape and previous disturbance can be used to help inform land use decisions. Restoration with these principles in mind ensures a focus on the ecosystem services that wetlands are capable of providing. A document by the National Research Council, summarized the importance of wetland restoration with the phrase “Restoration of wetlands has been observed to be more feasible and sustainable than creation of wetlands” (2001). The requirements of the memorandum to value ecosystem services may help decision makers to realize the functions and services present in the systems under their control. This realization can hopefully lead to restoration instead of degrading wetland and aquatic ecosystems only to attempt to recreate services elsewhere.

Some ecosystem services can be quantified in terms of a monetary value; an example is fishery production, where fish caught can be sold at a unit price, dollars per pound, in a real world market. However, some ecosystem services such as flood control are neither adequately quantified in commercial market terms nor comparable with manufactured capital. If a flood does not occur due to a properly functioning aquatic ecosystem, how can the true value be known? This leads to some ecosystem services not being weighed heavily enough in political decisions, despite the fact that some industries would come to a standstill without them (Costanza et al., 1997).

In the example of flood control, the function would be the aquatic and riparian system storing excess water, allowing it to discharge slowly and thus providing the service of flood mitigation. Some techniques to quantify services are by willingness to pay surveys or calculating the replacement cost. Looking again to the example of flood control, a willingness to pay survey would ask waterfront land owners how much they would be willing to pay to help prevent flooding damage. In many cases, no money is collected and the survey is only used to quantify the values of the services. Replacement costs calculate how much it would cost to put in a man-made structure that is supposed to yield the same services of the natural system. Replacement costs could be calculated by adding up the cost of building flood prevention structures along a reach of stream. These values are often ambiguous and generally cannot be applied across different projects. Much ambiguity is exacerbated by changes in monetary value, even though the ecosystem functions of the riparian wetland remain the same (Sheldon *et. al,* 2005).

Beaver Aquatic Ecosystems

The functions of aquatic and riparian systems provide services that are irreplaceable to humans. Aquatic and riparian systems generate a shifting mosaic of wet and dry meadows and forests, marshes, bogs, streams that “influence the climate, nutrient flow, vegetation, wildlife, hydrology” and even geomorphology (Hemenway, 2001). Aquatic and riparian functions can be grouped into three categories – biogeochemical functions that improve water quality, hydrologic functions that change the water regime in a watershed such as flood storage, and functions that provide habitat for plants and animals (Sheldon et al., 2005). Beavers play a vital role in creating and maintaining wetland dynamics, and can be used as a case study that displays the important roles wetland functions play in providing ecosystem services.

Ponding of a stream, often caused by beaver dams, can have substantial effects on the hydrologic regime. Beaver dams can decrease peak discharge and stream velocity, increase riparian habitat and water storage and elevate the water table (groundwater recharge). A study by Correll et al. (2000), found that annual discharge in a second-order stream in Maryland reduced by 8% in the presence of a 1.25-ha beaver pond. This reduced discharge and thus velocity is due to the water being stored in the floodplain that, without ponding, would discharge rapidly. This extra storage profoundly influences stream dynamics, providing invaluable services, especially during dry seasons or years. PHD research by Glynnis Hood, in Alberta in 2002 showed, using 54 years of historic aerial photos, records of beaver populations, and climate data that “ponds with active beaver lodges had nine times more water during droughts than ponds without dams” (Creek Restoration with Beavers, 2015.). Sullivan and Fisher (2011) saw similar effects an Oregon catchment. During dry periods, 30% of the water could be held in beaver ponds, increasing flows in late summer. This excess water may allow an intermittent stream to become perennial (Rosell et al., 2005). This function of water storage can have a profound effect, especially when dealing with the challenge of impending climate change which will cause a scarcity in water resources (Sullivan and Fisher, 2011).

Decreasing flood event severity is another ecosystem service of beaver dams because of the water storage function. When beaver dams are present and a flood events happens more water will be stored in the floodplain, thus dampening the peak discharge and allowing lower amounts of discharge over a longer time period. This benefit occurs as long as the dams don’t break in the flood event. In Alberta, beaver dam failure produced a flood 3.5 times the maximum discharge over the previous 23-year period (Rosell et al., 2005). Floods are a real issue for humans because of costs from damages and loss of life. The cost in property damages in the United States averages $7.96 billion annually (NOAA, 2015). The human fatalities associated with these flood events average 82 people per year (NOAA, 2015). The changing climate has the potential to increase the severity of these events in the future, making the need for these functions even more important.

The geomorphology of a stream channel is significantly impacted by the presence of beavers. Beavers introduce structural elements, dams and lodges, which significantly impact the discharge regime and sediment transport in a stream channel (Rosell et al., 2005). Beaver ponds function as sediment traps, accumulating organic matter in the process (Rosell et al., 2005) which can help incised channels regain access to their floodplains (Pollock, 2007). An average beaver dam, with four to eighteen cubic meters of wood, can retain 2000 to 6500 cubic meters of sediment (Hemenway, 2001). Streams that have been incised have had their beds down-cut and lowered.

Incised channels generally do not have much, if any, access to their floodplains, meaning high flows are concentrated within the channel and fish have no access to slow-water refugia during flood events. Further, nutrients cannot deposit on the banks, causing a detriment to terrestrial habitats. Incised channels have become more common, especially in semi-arid environments which used to contain gently meandering streams edged by dense riparian forests. Widespread trapping of beaver is a significant mechanism behind the shift from meandering streams to incised streams (Pollock, 2007). Woody debris input by beaver for dams, food, or dens is also an essential in-channel morphological feature because it increases the patchiness of bed sediment. Patchiness helps stabilize a channel by creating important stream features such as meanders, pools/riffles and islands (Rosell et al., 2005), all of which are important for biodiversity because they create niche habitats for plants and animals to occupy.

Water quality is an important service that is driven by the removal of sediments and nutrient cycling that aquatic and riparian functions provide. In streams where there are high levels of atmospheric pollution, beaver ponds assist in neutralizing acid by acting as a sink for $NO-_3^-$ and a source of NH_4^+, iron(Fe^{2+}) and manganese(Mn^{2+}) (Rosell et al., 2005). Alteration of freshwater nutrient levels has a strong impact on the productivity of the system. The sediments that accumulate behind beaver dams can hold upwards of 1000 times more nitrogen, N, per meter of stream than riffle areas, solely due to the excess sediment accumulation. A study by Naiman and Melillo (1984) found that in riffle areas most of the N was from allochthonous inputs, woody debris and leaf detritus, while in the beaver pond most of the N came from nitrogen fixation by sediment microbes. Francis *et al.* (1985) found that N fixation may be greater downstream of beaver ponds which was possibly linked to an increase in phosphorus, P levels. Beaver ponds accumulate organic matter, especially as anaerobic conditions decrease decay rates (Pollock et al., 1995). CO_2, a potent greenhouse gas, is sequestered from the atmosphere by these wetlands (Mander et. al, 2012). Wetlands could be considered the world's best ecosystems for capturing and storing the carbon from CO_2 due to a high volume of organic matter and low decomposition rates. When beaver are removed and dams destroyed, CO_2 is released into the atmosphere as floodplain soils dry out and oxidize (Creek Restoration with Beavers, 2015). These alterations to nutrient cycling create an overall more productive ecosystem, improving at all trophic levels and ultimately may help regulate climate change.

Wildlife

Habitat for animal populations is an important ecosystem function provided by riparian wetlands. Habitat provides a substantial list of ecosystem services that humans use, such as aesthetic value and hunting. In order to reap the benefits from the ecosystem services that wetlands provide, we need to restore and maintain the wetland ecosystem functions. Riparian wetland habitat encompasses the areas in and around streams- so both aquatic and terrestrial wildlife habitat must be considered when planning wetland remediation.

In Yellowstone National Park, the controversial re-introduction of wolves in 1996 had a positive impact on riparian wetland. Many studies, like the ones conducted by Ripple and Beschta (2012) and Smith et al (2003), have shown that wolves created a trophic cascade resulting in increased riparian wetland habitat. A trophic cascade is when a change in one part of a food web impacts lower parts of the food web. When reintroduced, wolves decreased the elk population. This smaller elk population led to less of a browsing impact on riparian vegetation. It has been observed that plant height increases were related to predation. Wolves not only improved the plant growth due to lowering the population of elk but also by changing the behavior of the elk. This improved plant growth was due to decreased browsing rates with increased predator risk (Ripple & Beschta, 2012), meaning plants in areas deemed a higher risk for elk predation were browsed less allowing the plants to grow (Ripple & Beschta, 2012). The vegetation, predominantly riparian trees such as willows, aspen, and cottonwoods, increased in height, stem diameter, canopy cover, as well as population size (Ripple & Beschta, 2012). These trees are important for birds, small mammals, beavers, and moose (Ripple & Beschta, 2012). Songbird richness has increased due to a more stable willow habitat in the Greater Yellowstone Area (Ripple & Beschta, 2012). Beaver populations have increased from one colony in 1996 to twelve in 2009 since their main food source, riparian trees, proliferated (Ripple & Beschta, 2012). The increase in beaver populations has led to more beaver ponds. These ponds are suitable habitat for amphibians, reptiles, and fish, therefore increasing populations of these animals. Browsing has also decreased for shrubs that produce berries. An increase in berry production means more food for other animals such as bears and birds (Ripple & Beschta, 2012). There is evidence showing that these changes are caused by wolf reintroduction as opposed to climate or other changes. This was concluded because the changes occurred in several woody species close to the time of wolf reintroduction (Ripple & Beschta, 2012).

Wildlife habitat is important for the ecosystem service of hunting. Conserving wildlife habitat increases biodiversity and richness. Wetlands provide migration, breeding, nesting, and feeding habitat for millions of waterfowl, shorebirds, songbirds, and other wildlife (LeGrange, 2004). Wetlands are unique in their density, diversity, and structure of vegetation. These factors along with the landforms found in riparian zones and wetlands provide the requirements for many wildlife species (Oakley et al., 1985). Hunters rely on these factors to have successful hunting. Increasing the habitat for an animal will increase the population of that specific animal. When the population of one animal flourishes, the populations of their predators also follow. With increases in population, the value of hunting as an ecosystem service increases.

Wetlands provide winter cover for game birds and ungulates (LeGrange, 2004). Vegetation that moderates temperature extremes is referred to as “thermal cover.” This vegetation keeps temperatures cooler in the summer, but also keeps temperatures warmer in the winter (Oakley et al., 1985). When riparian wetlands are restored, thermal cover increases and improves the habitat for game. In many areas during winter, particularly in severe winters, riparian zones and wetlands may be the only areas where snow does not render the habitat unsuitable to large and medium-sized mammals and to some forest birds (Oakley et al., 1985).

Habitat is an important ecosystem function that provides services to humans including aesthetics and hunting. A healthy habitat provides a thriving animal population that can then be hunted. Many species that have significant economic importance, such as most of the furbearers, as well as elk and deer that provide meat, are products of riparian zones and wetlands (Oakley et al., 1985). Wolves were reintroduced to the Greater Yellowstone Ecosystem as a management decision, but the trophic cascade the wolves influenced, increased the riparian and aquatic habitat. Many animals in this habitat benefited such as beavers, birds, and bears. As a result, the ecosystem services provided to humans by this riparian and wetland system were enhanced.

Productive Fisheries

Wetlands and estuarine habitats provide essential habitat for fishes and are of vital restoration importance to maintaining wild fish populations. These boundary zones between aquatic and terrestrial environments give fish species a safe place to spawn, lay eggs, and young fish to grow to maturity (Able, 2007). Unfortunately, with growth of human population much of this type of environment has been degraded and is in need of restoration.

Restoration success can be measured by changing plant communities, as well as fish and invertebrate abundance. In one particular study of wetland salt marsh restoration along Delaware Bay, in New England, restoration has shown measured success when compared to reference wetlands (Able, 2007). In this system, habitat loss occurred when natural salt marshes were removed. The natural salt marshes became separated from their tidal patterns of inundation and natural flow of water through the use of dikes and dams. The separation was done in an effort to create agricultural land for growing Salt Hay (*Spartina patens*) for its use as bed material and food for livestock. This form of agricultural production has occurred since colonial times as a valuable agricultural resource (Massie, 1998). As the urban areas grew, these salt marshes were also impacted by road construction, other agriculture, and urban sprawl. All of these changes remove the natural tidal flow of the wetlands, the habitat this creates, as well as the flood control and filtration capacities to the entire basin (Massie, 1998). These disturbances, as well as removal of the native grass species, *Spartina alterniflora*, occur across the salt marsh grass's range over nearly the entire coast of North America.

In the Able (2007) case study, two areas of traditional salt marsh were restored. The restoration was accomplished by removing the dikes that prevented tidal flow, and digging of new creeks into old agricultural land, to restore the tidal flow onto the floodplain and re-establish the native grass species and flow regime of the wetland (Able, 2007). This particular human effort allowed fish and wildlife to regain access to areas that were previously inaccessible except during brief periods of agriculturally induced flooding during the winter. Because of this change, 1,611 hectares of previously degraded habitat has been brought back into its natural tidal flow regime and plant community. This change has allowed for native fish species such as; *Fundulus heteroclitus, Menidia, Micropogonias undulates*, *Brevoortia tyrannus*, *Anchoa mitchilli*, and many other important fish species to return to the marshes for additional use as spawning and rearing habitat (Able, 2007). This additional habitat for young fish now provides the Delaware Bay ecosystem with significantly more fish to serve as food for larger fish, wildlife, and humans alike (Able, 2007).

This Delaware Bay Restoration project and other similar projects are taking place nationwide, and are vital to preserving ecosystem functions of productive fish populations. This ecosystem function provides humans with a suite of services that include valuable recreational and commercial fishing, and nutrient cycling and transport (Holmlund, 1999). Restoring and preserving natural wetlands for fish can best manage these services. Recreational and commercial fisheries can be measurable by the economic value they generate for their community. In Montana alone, commercial and recreational fisheries generate roughly $343 million annually towards the GDP (Erickson, 2015). This service develops economic prosperity for the community around the fishery ecosystem, as well as provides a valuable food source that has existed for millennia (Fish and Wildlife, 2015). This service also benefits the wildlife, that depend on wetland ecosystem, as a valuable food source for Bald Eagles, Grizzly Bears, marine mammals, and other wildlife. This benefit, further economically benefits the human community in the form of tourism dollars generated by wildlife viewing such as bird and whale watching among other wildlife (Erickson, 2015). This economic benefit is the most easily measurable service generated by a productive fishery and provides the most support for restoration as a means to economic prosperity of the region surrounding wetlands.

Healthy and productive fish populations also provide the ecosystem with functional nutrient cycling that would not be present without fish to accumulate and redistribute nutrients. This service comes in many forms, but the most prevalent is making nutrients available to the environment in the form of food web dynamics that result in consumption and excretion where nutrient rich fish and invertebrates are broken down into available Nitrogen and Phosphorus (Holmlund, 1999). This process takes nutrients previously locked up in the tissues of aquatic species and makes them available to plants, bacteria and invertebrates upon excretion. This dynamic process keeps trophic levels in contact from the top down, as predator fish control the variable levels of lower trophic level species, while also providing food and nutrient sources to these species (Holmlund, 1999). Some species of fish, specifically migratory and anadromous species, play a key role in transporting nutrients from oceans back to the streams and wetlands where they are born. These species, such as Salmon and Steelhead, return from the ocean to the streams and wetlands where they were born to spawn and eventually die, bringing with them nutrients previously lost to productivity downstream (Holmlund, 1999). This service plays a vital role to salmon streams along the Pacific Coast. In some studies, these marine derived nutrients found in returning adult Salmonids provide the stream with as much as 20-40 percent of the annual nitrogen and phosphorus inputs to the stream in the form of eggs and adult carcasses deposited in the stream after spawning occurs (Holmlund, 1999). These significant marine nutrient impacts have been found to supplement stream communities as many as 50 km downstream of spawning habitats, and as far as 1000 km from the ocean (Holmlund, 1999). This impact helps sustain the fish and invertebrate communities required to maintain healthy and productive fisheries. These and many other services provided by a self-sustaining fishery and healthy wetlands are irreplaceable, and justify our dedication to keeping services in mind in wetland restoration.

Conclusion

With maintenance and preservation of aquatic and riparian systems, ecosystem services can be improved, therefore reducing costs and improving life for humans. These services can only be provided by certain functions of an ecosystem. With the recent memorandum, the valuing of ecosystem services will hopefully become clearer as agencies are forced find a cohesive definition and incorporate services into planned work. Restoration of the physical, biological, and chemical processes within aquatic and riparian systems can improve ecosystem services. In this paper, the three functions of wildlife habitat, water storage, and productive fisheries were looked over in detail. With the restoration of riparian habitat, species biodiversity can be improved. Riparian wetlands allow for the system to self-regulate, sometimes with the help of ecosystem engineers (i.e. beavers). This is done by altering stream hydrology, leading to reduced flood damages that can cost home owners and the government millions of dollars per year. The slowing of water facilitates positive changes in water chemistry and nutrient cycling as well, helping water quality and increasing biodiversity. These rich and diverse systems can increase aesthetic beauty that has a monetary value seen in the increase of property values as people want to be closer to improved areas. This network can also add to the availability and quality of game species that provide sport and income for many people. Productive fisheries are directly linked to the aquatic and riparian ecosystems that provide particular conditions for habitat and cover. These productive fisheries not only benefit the ecosystem through nutrient cycling but also the humans that depend on them for recreation, economic stability, and food. The maintenance and restoration of ecosystem functions and the associated services needs to be a priority, especially with a growing population in an ever-changing climate.

Functions and Services of Riverine Ecosystems

Wyatt Anthony, Chris Kubicki, Simon Fordyce, Emery Three Irons

On October 7, 2015, the White House issued a memorandum directing Federal agencies to incorporate considerations of ecosystem services into environmental planning and decision-making processes. The document defined ecosystem services as "the benefits that flow from nature to people." In other words, ecosystem services are the human benefits obtained from ecosystem functions, where ecosystem functions are defined as the biotic and abiotic processes occurring in an ecosystem. The memorandum stated that "characterization of ecosystem services may be accomplished through a range of qualitative and quantitative methods to identify…monetary and nonmonetary values for those services" (Whitehouse 2015).

Conservationists commonly attach monetary values to ecosystem functions based on the services they provide. The reframing of ecosystem functions as ecosystem services (henceforth 'the ecosystem services construct') promulgates the idea that ecosystems are worthy of conservation *because* they provide benefits to humans. During the Dust Bowl of the 1920s, U.S. Soil Conservation Service used this approach to reframe soil erosion as an economic problem, and in doing so the agency successfully persuaded farmers to adopt conservation-friendly practices. Despite success stories like this, some scholars are questioning the efficacy of the ecosystem services construct, concerned that the valuation of ecosystem functions based on human benefits (often economic benefits) does not adequately characterize the inherent value of ecosystems. For example, Peterson et al. (2010) warn that the ecosystem services construct amounts to Marxist commodification of ecosystem functions. The team argues that "just as it obscures the labor of human workers, commodification obscures the importance of the biota (ecosystem workers) and related abiotic factors that contribute to ecosystem functions." Similarly, Odum and Odum (2000) describe a need to valuate ecosystems more inclusively: "When human valuations do not measure the real contributions of natural ecosystems, as is currently the case, ecosystems are not protected." Furthermore, some ecosystem functions can be valuated very easily in terms of human benefits, and others cannot. Thus, there exists a need to measure "the real contributions" of ecosystems by means that do not rely on the ecosystem services construct. Put simply, we must value ecosystems for the sake of ecosystems, not for the sake of the services they provide.

Despite the potential shortcomings of the ecosystem services construct, federal agencies are now obliged to valuate ecosystem functions based on ecosystem services. It is therefore critical that policy-makers understand these two terms and the subtleties between them. Here we provide a detailed discussion of ecosystem functions and services as they relate to riverine systems. Riverine systems can provide many services to humans (e.g., natural purification of water, erosion control, habitat for fish and wildlife, recreation, etc.), but human activities often threaten these services. This paper outlines the ways in which timber harvesting, riparian zone degradation, and damming can threaten the ecosystem services and functions afforded by rivers. Authors aim to improve the reader's understanding of the ecosystem services construct.

Timber Harvesting

Timber harvesting can have a negative impact on water quality in a variety of ways. Irresponsible timber harvesting practices can have an immense impact on the structure of a watershed and when compounded by runoff and other natural processes, these alterations to the watershed can have a severe effect on water quality. Watershed degradation affects many aspect of water quality, such as increasing sediment load and nutrient concentrations. Logging has the ability to affect water quality in numerous ways. Practices associated with timber harvesting affects water quality by creating changes in nutrient concentrations, turbidity and sedimentation, and water temperature (Corbett et al. 1978). Although the effects from timber harvesting can be attenuated through best management practices, their effects still remain pervasive in watersheds managed for timber harvest.

Vegetation removal by logging can be attributed to changes in nutrient cycling in an ecosystem. With decreased plant cover, nutrients can be leached more rapidly, thus increasing nutrient concentrations that reach streams. Clear cutting exposes the soil to more sunlight, therefore raising the soil temperature and the decreased vegetation also results in a diminished uptake of water by plants. This increase in soil water content and temperature expedites the process by which organic matter is broken down, resulting in an increase in the rate of nutrient leaching and amount of nutrients leached (Corbett et al. 1978). Typical logging operations create only a slight change in the nutrient cycling rate, but extreme cases such as the Hubbard Brook experiment result in a significant increase in nutrient leaching (Corbett et al. 1978). This increase in nutrients can be seen in Figure 1, which shows a clear-cut site (Watershed 2) compared to an unlogged control site (Watershed 6) (Likens et al. 1970). This figure clearly shows how the removal of vegetation results in a significant increase in Nitrite. Notice the scale change on the y-axis.

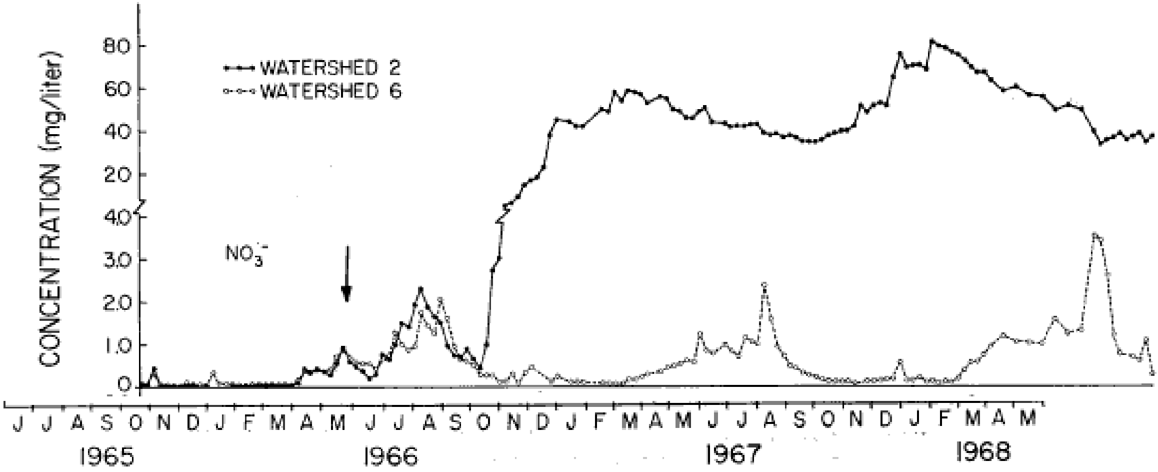


Figure 6. Graph from Likens et al. 1970 displaying an increase in Nitrite concentrations as a result of clear cutting

These high concentrations of nutrients eventually end up in a waterway where resulting algal blooms create oxygen depletions, which often leads to large fish kills (MPCA 2008). This level of impact to ecosystem function will degrade ecosystem services important to humans, such as fish kills that are large enough to destroy the fishery in that area. Algal blooms result in lakes and streams that are generally aesthetically unpleasing as well as produce unpleasant smells. All of the alterations to the ecosystem affect how the ecosystem functions and consequently what services can be provided to humans.

Erosion is a big impact of logging which will increase the amount of sedimentation and turbidity in a stream. If logging operations are carried out effectively and in an environmentally minded way, the extent of erosion can be limited; however, erosion can never be completely avoided. The degree to which erosion occurs can vary dramatically depending largely on variations in climate, topography, geology, and soils (Corbett et al. 1978). Clearly, the removal in vegetation will increase erosion by decreasing precipitation interception leading to a higher runoff coefficient (Lewis 1998). Higher volume of overland flow will mobilize more sediment down gradient to a stream. Once in the stream these eroded sediments create turbid water, which not only has an effect on the aesthetic appeal of the ecosystem, but also on the cost of water treatment and the integrity of fisheries. The increased sediment load means that water purification systems must work harder to purify the water, which comes at a cost. Turbid waters also have numerous effects on fish such as improper gill formation and the prevention of egg development (MPCA 2008). These effects along with others can have a significant effect on a fish population. Vegetation loss also results in a reduction of transpiration (Lewis 1998). Trees and other plants remove water from the soil for photosynthesis and some of this water is lost from their leaves or needles due to evaporation. When trees are removed from a watershed there is an increase in the amount of water leaving the ecosystem. The effect of decreased interception and transpiration from removing trees result in wetter soils and this along with the decreased root strength can lead to more unstable slopes (Lewis 1998).

The use of skidders and cutters in industrial logging practices creates unnatural drainage paths and soil compaction, both of which lead to an increase in erosion. Compact soils decrease pore space and changes the rate and amount of water that infiltrates the soil. Decreased water infiltration results in more runoff and greater stream turbidity. While logging practices such as felling, yarding, and skidding causes increased erosion and result in an increase in stream turbidity, these effects are negligible compared to the sediment production that is generated through road construction to aid in logging practices (Megahan and Kidd 1972). The study conducted by Megahan and Kidd in 1972, found that logging operations alone, excluding road use and construction, increased sediment mobility by a factor of 0.6 (60%). Roads on the other hand account for an increase of 750 times the natural rate of sediment transport. This increase in sedimentation leads to higher stream turbidity, which impacts the ecosystem services provided to humans. Sediments can become deposited on stream beds and fills the pore spaces between coarse fragments. This deposition of fine sediments results in a reduced macroinvertebrate habitat and reduced populations of these organisms. This reduction in macroinvertebrate population leads to degradation of a fishery as the food source for these fish is depleted. Increased turbidity also leads to an increase in cost of water purification before it can be used for human consumption. Services like aesthetics and recreation are also impaired by increased turbidity, therefore decreasing some of the services provided to humans.

An increase in water temperature can inhibit the in-stream ecosystem functions, which will then alter the ecosystem services provided to humans. For example, many salmonid species cannot survive under increased thermal stress. Increased water temperature means that the water can hold less dissolved oxygen making it harder for salmon to exist at this temperature, and this can then lead to a reduction in the service of providing food and recreation to humans. Logging increases stream temperature by exposing more of the water surface to direct solar radiation. Streams in natural, unlogged settings are surrounded by a forest canopy, which diffuses the solar radiation, reducing the solar heating of the stream (Corbett et al. 1978). Increases in water temperature affect the functions of the river ecosystem by changing the rate of nutrient cycling, reducing fish habitat, and impairing the health of poikilothermic stream organisms. These functions impact the services the stream provides to humans. It is possible to conduct timber harvesting operations that have little effect on stream temperature; however, unsustainable practices such as clear cutting can be a significant detriment to stream temperature. Extreme cases like the Hubbard Brook experiment (Burton and Likens 1973) where the watershed was clear cut and herbicides were applied to completely remove all plant growth. This caused stream temperatures to increase drastically with an average stream temperature increase of 7.8°C in the clear-cut site on the first July after treatment (Burton and Likens 1973). Similar results were observed for a clear-cut study site in Oregon where a 7.8°C increase in the maximum annual stream temperature was recorded (Brown and Krygier 1970). The temperature changes observed in the two case studies would be sufficient in reducing the ability of many fish species to survive in that particular habitat.

The effects of logging on stream temperature can be mitigated by leaving buffer strips around streams. This maintains the natural canopy around the stream and prevents the water surface from receiving increased solar radiation. This buffer not only preserves water temperature, but many other aspects of water quality dependent on the riparian zone. The services the buffer strip provides to humans are aesthetic appeal created by the preservation of the riparian zone, bank stabilization, and moderation of stream temperature which supports native fish species.

Riparian Buffers

Much like the benefits provided by vegetative buffer strips left intact around streams during logging practices, riparian areas support numerous ecosystem functions that also result in the provision of services to humans. Riparian areas are the connection between waterways and surrounding land. These areas influence properties of water and the stream, including storage capacity, ground water, plant productivity, biodiversity, organic matter quality, pathways for chemicals, and protect streams from distribution of sediment and chemicals (Osborne and Kovacic 1993). Riparian areas are affected by a variety of conditions within an ecosystem such as sediment and nutrient loads that are transported by runoff during rain events. Riparian areas provide habitat for aquatic and terrestrial organisms. These areas also enhance aquifer recharge, biodiversity, and the ability to cycle nutrients within streams (Osborne and Kovacic 1993). Riparian areas also provide services such as: clean river systems, recreational use, bank stabilization, and flood mitigation. The focus of this section is to explain the use of riparian areas to serve as a buffer strip, which can be beneficial by limiting the input of nutrients to a stream system.

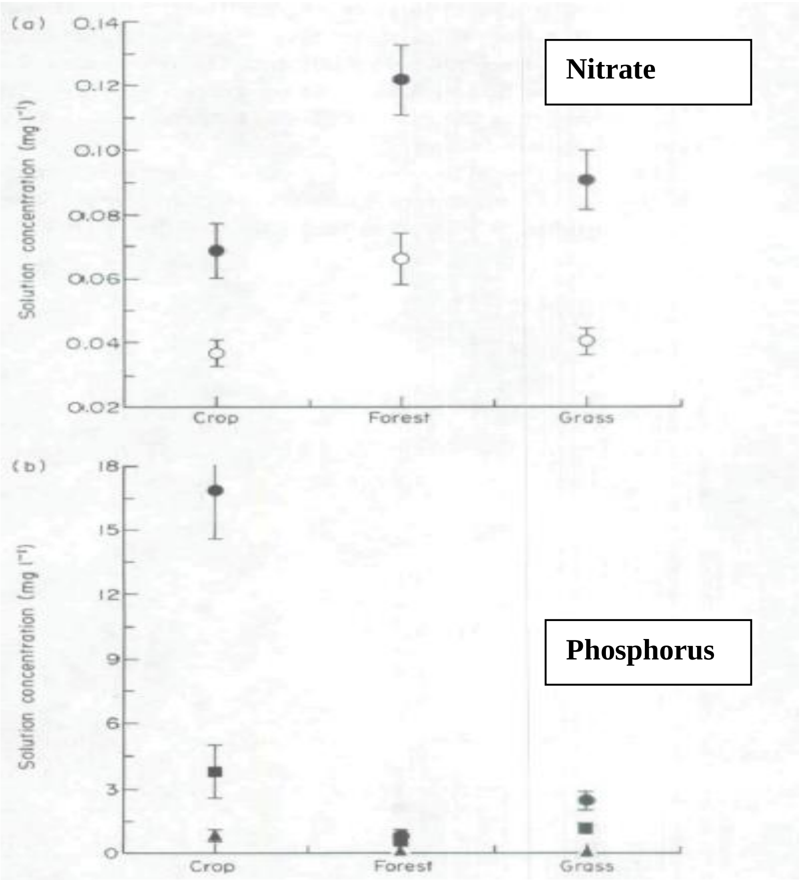


Figure 7. Riparian zones effect on in nutrient concentrations

Riparian ecosystems can increase or reduce, alter or integrate a substance traveling through the system (Osborne and Kovacic 1993). Many processes are attributed to riparian areas, these processes include: storage capacity, aquifer recharge, primary and secondary productivity, organic matter quality and quantity, and biogeochemical pathways and rates. These ecosystem functions contribute to ecological services such as reducing sediment and nutrient loads that affect water quality (Osborne and Kovacic 1993). Sediment loads enter water ways through runoff accelerated by reduced vegetation, erosion and other factors like slope and particle size that affect water quality. Sediment loads can be reduced in streams by using narrow vegetated buffer strips which moderate nutrient and sediment loads (Osborne and Kovacic 1993).

The structure of riparian ecosystems increases soil stability and decreases the amount of nutrients being input to the stream. Buffer strips act in a similar manner to riparian vegetation. These buffer strips also preserve many of the ecosystem functions that a riparian area would. These riparian areas provide a service to humans through improving water quality by reducing sediment and nutrient inputs.

Agriculture practices also affect stream water quality. The use of fertilizers on crops has potential to runoff into streams after rain events. Riparian ecosystems help mitigate nutrients entering streams. A particular function of buffer strips is reducing nutrient load problems (Osborne and Kovacic 1993). In an experiment done by Osbourne and Kovacic they look at riparian buffer strips ability to remove nutrients. The study looked at the effects of multiple vegetation types on nitrogen and phosphorus concentrations in the water. The vegetation included two different species of hardwood trees and a perennial bunchgrass that were used for the buffer strip and the crops include corn and soybeans. The upland zone was planted with row crops of corn and soy bean. The tested riparian area consisted of three treatments to measure the effects of the buffer strips. First, a forest of cottonwood (*Populus deltoides*) in a 16m buffer strips and silver maple (*Acer saccharinum*) and a buffer strip of 39m of reed canary grass (*Phalaris arundinacea*) were in between the stream and row crops. Lysimeters and piezometers were used to measure nutrient movement after precipitation events.

The results indicated no difference in the concentration of nutrients in the upland crop area (Figure 2.). In the riparian zone, concentrations of dissolved and total phosphorus were higher in the forest than the crop and grass buffer strips. In the crop areas there was no difference between the riparian and upland of nitrate levels. The figure illustrates riparian forest is nitrate limited; however, the system is not phosphorus limited. This shows that the forested system is more efficient in removing nitrate than phosphorus. Both the grass and forest buffer strips reduce nitrate in shallow groundwater, but the forest is more efficient at reducing nutrient concentrations than grass on an annual scale. Overall the results revealed nitrate levels were not as concentrated indicating that removal of nitrate was significant in the riparian area and forested buffers were more capable in reducing nitrate, but not phosphorus (Osborne and Kovacic 1993). The results for the buffers effect on sediment loads is inconclusive; therefore, further research is recommended to determine long term effects of using vegetated buffer strips to reduce sediment loads entering streams. The reason being that experimental data indicate sediment loads actually increased over time (Osborne and Kovacic 1993).

Stream ecosystem functions are complex with entwined processes that involve many parts, from inputs of water and energy; vegetation and soil type each with a role altering the movement of water through the riparian area. Vegetated buffer strips help reduce nutrients entering streams; however, limitations using these methods include drainage areas of the agricultural land use, the presence of anaerobic conditions to denitrify and reduced nitrate concentrations, and constant care of forested and grass buffer strips to maintain efficiency.

Dam Removal

The use of dams to tame often unpredictable rivers has been used since ancient times originating in Mesopotamia and the Middle East (Fahlbusch 2009). Modern dams provide such services as electric power, water for irrigation, and drinking water (Brismar 2002). While providing many anthropogenic benefits, dams also negatively alter riparian ecosystems (Scudder 2012). For example, dams typically raise flood water levels (Maclin 1999), and disturb natural fisheries which can have major ecological and economic consequences (Raymond 1979). They also trap fine sediment, resulting in erosion of the stream bed and banks downstream of the dam. Moreover, most of the dams in the U.S. are no longer intact; Almost 85% of dams in the United States will no longer be operational by 2020 (Doyle 2003). As a result the removal of dams is a growing practice within ecological restoration. In this section, we will analyze how dams affect water quality and how dam removal typically enhances water quality. We will also look at other ecosystem services and functions enhanced by dam removal.

The Dead Lake Dam located on the Chipola River in Florida was removed in December of 1987, and the total cost of removal was $32,000. This dam was originally put in place in 1960 by the Army Corps of Engineers to stabilize flows and prevent low flow events. The lake created by the dam showed significant increases in organic matter and signs of eutrophication, which are excessive nutrients within a body of water resulting in dense plant growth and a reduction of dissolved oxygen (Smitha 1999). 1987 the Dead Lake Dam was removed. The major ecological functions restored by this dam removal were increased species richness and an improvement of the water quality, along with fluctuations in water flow (Hill 1994). The ecological services provided from the increased species richness were an improved fishery, which benefited the surrounding community by providing more fish to eat and sell, along with attracting recreational fisherman to this area (Maclin 1999). The improvement of water quality provided the ecological service of increased fish habitat, cleaner drinking water, and improved aesthetics of the stream (Maclin 1999). However the Dead Lake Dam removal raised the original problem of less predictable flow fluctuations. Yet, the fluctuating water level actually increased the spawning ground for the fish populations and increased the dissolved oxygen content of the stream (Maclin 1999). This is a good example of how dam removal improves both water quality along with multiple other ecosystem services and functions (Maclin 1999). The next example will look at a dam removal site which the benefits are less clear.

Dams often collect fine silts and sand. Depending on the dam and how it is removed, the sediment can either be beneficial or harmful to the system. An example of sediment damaging a system is the Fort Edwards Dam removal located on the Hudson River in New York; upon removal 30,000 cubic yards of bedload materials were released downstream (Maclin 1999). This sediment released contained polychlorinated biphenyl contaminates along with raw sewage, which cost the state of New York thousands of dollars to remove (Maclin 1999). Navigation channels had to be closed during 1974 along the stretch of river below Fort Edwards dam (Maclin 1999). While the majority of the built-up sediment typically flushes out of most systems within a matter of days, the effects of sediments being released from Fort Edwards Dam is estimated to last up to 80 years (Simons 1991). The Elwha dam removal (which will be discussed extensively later in this section) released more than 34 million cubic yards of sediment, but had a completely different effect than the Fort Edwards Dam removal. The sediment released from the Elwha improved fish habitat and built beaches along the river, the species *Thaleichthys Pacificus* (a small bait fish) returned to the area after a 70 year absence (United States. National Park Service. “Elwha River Restoration”). Slowly drawing down the water level behind the dam, using screens to trap sediments, and dredging of the reservoir are all options that can also be used to mitigate the effects of excessive stream sediment (American Society of Engineers 1997). Having a thorough understanding of the role sediment plays in a particular river is essential to a successful dam removal.

There have also been times were removing a dam has actually decreased the biodiversity of the ecosystem; such was the case in the removal of the Fulton Dam on the Yahara River, Wisconsin. Wet meadow grasses replaced *Typha* (Cattails) and *Cyperaceae* (Sedge), as a result the duck and muskrat populations, who relied on cattails for habitat, decreased (American Society of Engineers 1997). With proper foresight and knowledge of the river this issue could have been avoided.

Cultural value is a service provided by dams not typically thought of. Hoover Dam is an example of a large dam that has gained cultural significance and as a result is now a major tourist destination with 7 million visitors annually (United States. National Park Service "Hoover Dam"). The Hoover Dam provides hydroelectric power and drinking water to major cities in the southwestern US. Ecologically, the impacts of this dam have been devastating; specifically to the ecological functions of the Colorado River. The major ecological functions affected are habitat for fish and vegetation, species richness, species diversity, reduction of natural flooding, and changes in salinity of the water downstream of the dam (Glenn 1996). Though the dam is detrimental to many river functions, removing the dam would decrease engineered services; the southwest would lose a large supply of their drinking water, Nevada would lose tourists, and the popular recreation area created by Hoover Dam (Lake Meade) would disappear. While not ideal, it seems the Hoover Dam's benefit to society outweighs its ecological impacts. This is an exception to most dam removal situations.

A general theme throughout these case studies is that there is great variation between different dams, with a different solution for each project. The ecological functions of a river take a long time to be restored when a large dam is removed and isn't initially cost effective. For smaller dams the exact opposite is true, removing the dam is often more cost effective and more effective at restoring ecological function (Doyle 2003). Scientists are discussing the creation of a classification system of dams to assist with assessing a dam's ecological and cultural value (Poff 2002). There is also a clear link between dam creation and policy, but less so for dam removal is lacking partially due to the absence of critical science needed to create these policies (Doyle 2003).

The most recent dam removed is of the Elwha Dam in Washington State. The Elwha dams were constructed in 1910 in Calallam County, Washington with the intention of being used for hydroelectric power. The dams created a barrier for anadromous salmon preventing them from reaching 130 km of habitat within Olympic National Park (Brenkman 2008). The dam also deprived the lower stretch of river from sediments resulting in erosion of the stream bed (Figure 3.). The ponding created by the dams created two lakes, Lake Aldwell and Lake Mills, which resulted in warmer water behind the dam. The increase in water temperature affected the salmonid habitat and increased parasite populations (Miller 2011). This research along with the Elwha River Ecosystem and Fisheries Restoration Act enacted in 1992 helped drive this dam removal effort. There was also a large amount of public support from the Lower Elwha Klallam Tribe (Duda 2008). Prior to removal there were concerns that the 18 million m^3 of sediment being stored by the dam would damage the anadromous salmon below (Brenkman et al. 2008). The issue of sediment deposition was addressed using a procedure for slowly drawing down the lakes so that not all of the sediment would be released at once. Upon removal it appears that the stream was able to remove and store the appropriate amount of sediment without harming the anadromous salmon (East 2015; Frick 2014). Overall the Elwha dam removal increased the ecological functions of greater species richness and water quality, which increased the ecological services of aesthetic appeal and recreational fishing. Monitoring still needs to be done to ensure the salmon make a full return.

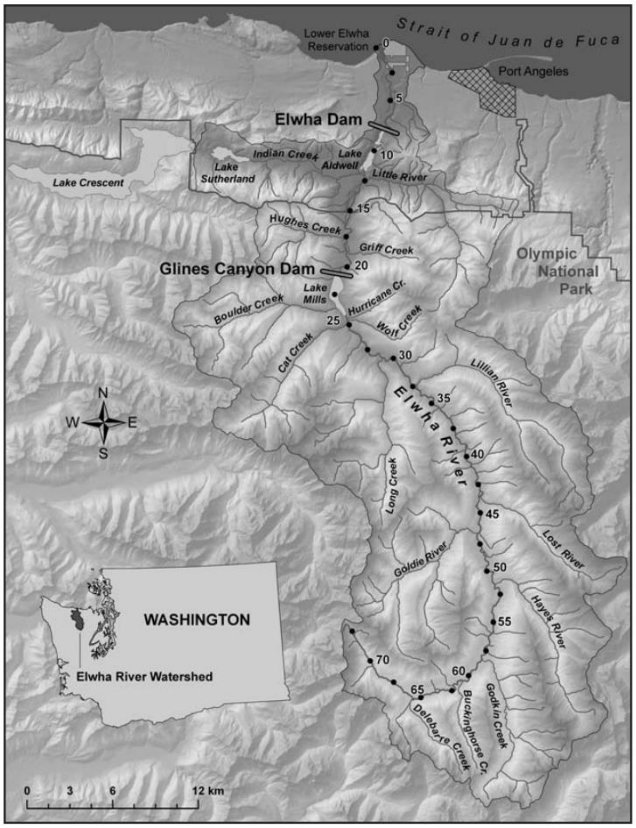


Figure 8. Map of the Elwha River showing Elwha and Glines Canyon Dam (Brenkman et al. 2008)

Though there are possible negative ecological impacts associated with dam removal there is a large body of work showing that dam removal typically increases sediment transport, decreases massive floods, increases native fish populations and improves water quality. Typically, these benefits outweigh the drawbacks of dam removal. A thorough understanding of the history of a river, its ecology, its physical components, and it cultural role all play very important parts in determining whether or not dam removal is appropriate. Looking at these variables and determining their ecological functions and ecological services can help make this decision easier. Hopefully scientists and policy-makers work together to ensure our rivers provide the functions and services needed the most.

Conclusion

The terms *ecosystem functions* and *ecosystem services* are often used interchangeably among scientists and policy-makers alike. The purpose of this document was to minimize confusion surrounding the two terms and to delineate the subtleties that set them apart. We discussed a variety of riverine functions and services threatened by timber harvesting, riparian zone degradation, and damming. It is the authors' hope that readers come away with an improved understanding of functions and services as they relate to human disturbances such as these. Because federal agencies are now obliged to incorporate considerations of ecosystem services into environmental planning and decision-making processes (Whitehouse 2015), it is of utmost importance that scientists and policy-makers have a firm grasp on the nuances of the ecosystem services construct.

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