Accounting for Maryland's Ecosystem Services:

Integrating the value

of nature into decision making

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DEPARTMENT OF
NATURAL RESOURCES

&Chesapeake
Coastal Service

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Executive Summary

Ecosystem services can be broadly defined as any benefit that people receive from the environment. The ecosystem services we consider in this report are those that have quantifiable monetary value. We assess that monetary value by looking at how people pay for an ecosystem service in a market, or what they would have to pay to replace or conserve the service. By looking at multiple instances of economic preference we estimate the "social value" of ecosystem services.

When ecosystem services are lost they must be replaced through restoration or with manmade alternatives, or the public must do without those benefits. If they are not replaced we will eventually suffer the consequences, be it through human health impacts due to poor air or water quality or a decrease in opportunities to enjoy a healthy ecosystem through wildlife watching, hunting, or fishing. In both of those cases there are real consequences to both our quality of life and economy in Maryland.

The values contained in this report are intended for evaluating tradeoffs and informing decision making, but do not indicate market value or compensatory value. While in some cases we consider market values as part of the value equation, the assessment broadly quantifies the many ways people value the natural environment, yielding a "social" or "public" value of ecosystem services in Maryland.

The economic value of ecosystem services from natural lands in Maryland is significant, totaling $8 billion every year for the seven non-market services we value here. For comparison, the economic impact of the agriculture sector in Maryland totaled $8.25 billion in 2013. Stormwater mitigation is the largest service from natural systems, totaling $3.1 billion, followed by wildlife habitat at $2.6 billion. Groundwater recharge, nutrient uptake, surface water protection, carbon sequestration, and air pollutant removal total $1.3 billion, $417 million, $247 million, $235 million, and $141 million of benefits per year, respectively. These values are in addition to the marketed economic contributions from outdoor recreation and resource extraction.

Table of Contents

Figures

Tables

The Natural Resources of Maryland

The people of Maryland benefit from the natural environment in many different ways. Forests clean the air, wetlands clean the water and the Chesapeake Bay provides fish and crabs. These benefits people gain from the environment can be collectively referred to as **Ecosystem Services (ES)** (

Figure 1). Though ecosystem services can be categorized in different ways[1,2], they are commonly divided into four major categories: **provisioning services** (e.g. timber, firewood, food), **regulating services** (e.g. water purification, wildlife habitat), **supporting services** (e.g. nutrient cycling, soil formation) and **cultural services** (e.g. recreation, spiritual benefits).

Photo Credit- DNR Photo Contest – Justin Prahl 2014

[1] Millennium Ecosystem Assessment (2005)
[2] Boyd and Banzhaf (2007)

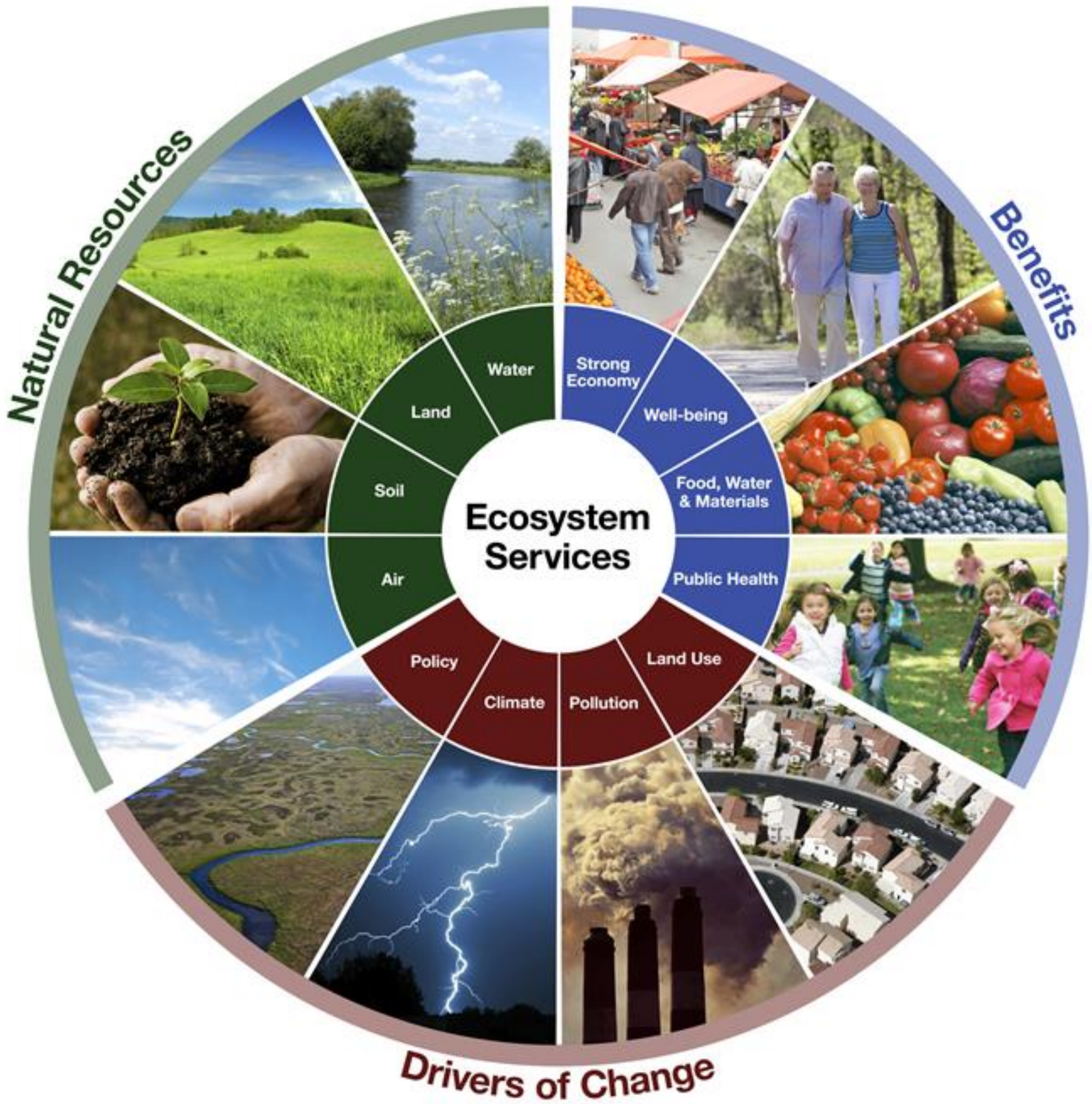


Figure 1. Natural resources provide benefits, subject to drivers of change (from US EPA EnviroAtlas, 2016)

Table 1. Ecosystem services in Maryland.*

Ecosystem Service	Forest	Freshwater Wetlands	Coastal Wetlands	Chesapeake Bay	Crop Agriculture
Reduce Stormwater Runoff	+	+			+
Control Flooding		+	+		+
Recharge Groundwater	+	+			+/-
Uptake Nutrients	+	+	+		
Reduce Air Pollutants	+				
Sequester Carbon	+	+	+	+	+/-
Wildlife Habitat	+	+	+	+	
Food Provision	+			+	+
Recreation	+	+	+	+	
Timber	+				

*The + symbol indicates that the ecosystem type provides the service, the +/ – symbol indicates that the system can either have a positive or negative effect on the service.

Maryland is the eighth smallest state in the United States, comprised of 9,772 square miles but has the 15th largest economy with a state domestic product of $378.3 billion dollars in 2016[3]. During the recent economic recession Maryland was one of the few states to maintain economic growth, due to a strong reliance on employment and spending of the federal government, the high tech industry, and trade. Farming contributed $8.25 billion to the Maryland economy in 2012[4] and commercial fishing in the Chesapeake Bay contributed $1.8 billion in direct sales in 2012[5].The forestry industry in Maryland is the 5th largest industry in the state, employing 14,000 people and generating approximately $2.2 billion dollars annually[6]. Maryland is known for its diversity and is referred to as Little America or America in Miniature due to the high variability in climate, geology, elevation, and ecology. Maryland has five distinct terrestrial physiographic regions and surrounds the majority of the Chesapeake Bay, the largest estuary in the United States.

Maryland's Physiographic Regions

Maryland is located in the Mid-Atlantic region of the United States and is comprised of five physiographic regions. Going from east to west the physiographic regions are the Coastal Plain Province,

[3] Bureau of Economic Analysis (2017)
[4] Ferris and Lynch (2013)
[5] National Marine Fisheries Service (2014)
[6] Rider (2010)

the Piedmont Plateau Province, the Blue Ridge Province, the Ridge and Valley Province, and the Appalachian Plateau Province. The majority of the state is at a relatively low elevation, as evidenced by the fact that the average elevation is only 348 feet above sea level.

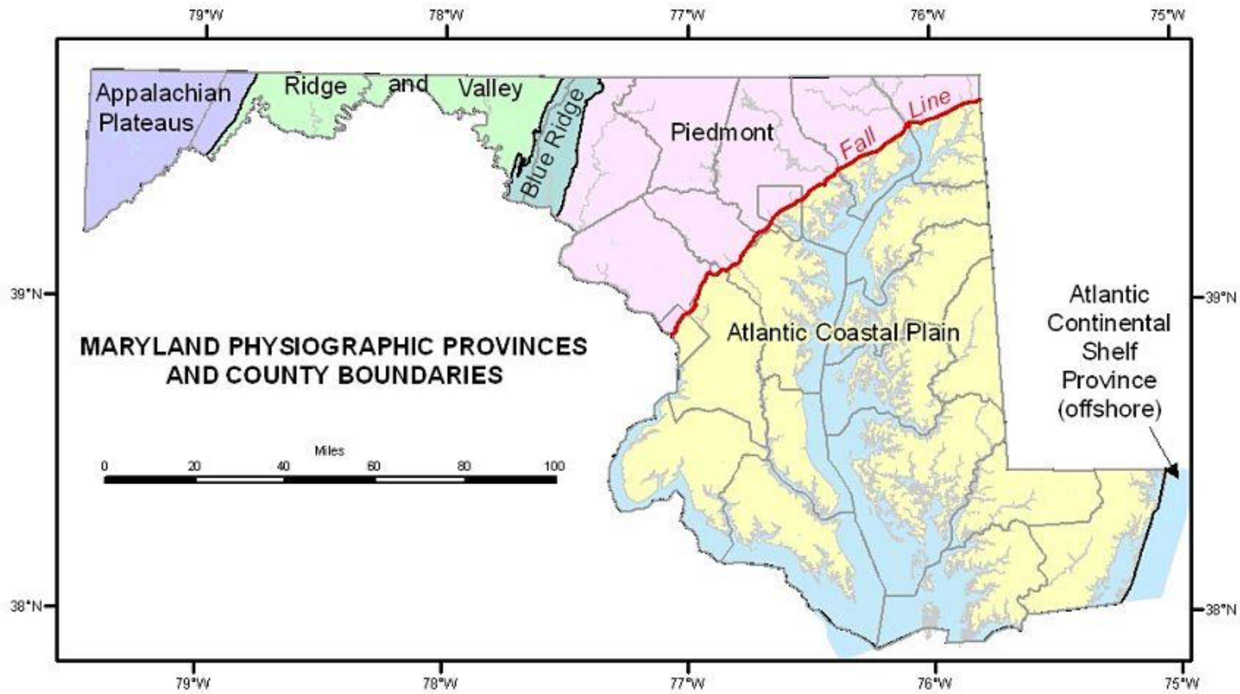


Figure 2. Physiographic regions in Maryland. From Maryland Geological Survey.

Middle Atlantic Coastal Plain

This Eco-region encompasses the eastern and western shores of the Maryland portion of the Chesapeake Bay, nearly one half of the state's total land area. This region has abundant wetlands, both coastal and freshwater and has a relatively flat elevation. The dominant forest types are loblolly-shortleaf pine and oak-gum. The Coastal Plain Province is comprised of deep unconsolidated sediment, ranging from 7,874 to 39,370 feet. These sediments support several deep aquifers in this region.

Northern Piedmont

The fall line (the region where hard crystalline bedrock meets softer sedimentary bedrock) forms the boundary between the Piedmont and Coastal Plain eco-regions in Maryland. Elevation begins to increase in this region and Oak-Hickory forest dominates. In contrast, the Piedmont Province is composed primarily of igneous and metamorphic bedrock such as schist, gneiss, gabbro, phyllite, slate, and marble. This hard substrate does not support large aquifers.

Blue Ridge, Ridge and Valley, and Appalachian Eco-Regions

A small stretch of the Blue Ridge eco-region is in Maryland and is dominated by mixed oak forests. Extending south, the Blue Ridge eco-region is one of the most biologically diverse regions on the east coast of the United States, supporting many endemic species. The Blue Ridge region is underlain by igneous and metamorphic rocks. The Ridge and Valley and Appalachian Provinces are somewhat similar geologically. They are underlain by folded and faulted sedimentary rock; minerals commonly occurring in these regions are quartzite, limestone, shale, sandstone, and dolomite[7].

These eco-regions become increasingly mountainous and are dominated by mesophytic (moisture loving, due to the high rainfall) mixed oak forest. The highest elevations in Maryland are in the west with the highest point being Backbone Mountain at 3,360 feet above sea level.

Maryland's Climate

Maryland is diverse climatically considering that it is a small state. The western portion of the state averages lower temperatures and less precipitation (average of 48° F and 36 in at the extremes) than the eastern part of the state (with state high annual averages of 59° F and 48.8 in). The Chesapeake Bay and Atlantic Ocean play a major part in ameliorating temperatures and promoting rainfall in the eastern portion of the state while the higher elevations of the Appalachian Mountains in the west create lower temperatures.

Forests in Maryland

Forests in Maryland provide many benefits to people. They help to maintain air and water quality, build and maintain soil, sequester carbon, and provide habitat for wildlife, maintaining biodiversity, along with providing recreational opportunities and timber, forming the base of the forest products industry. The state of Maryland is 40% forested, covering 2.7 million acres of land[8]. Seventy six percent (76%) of forest land in Maryland is privately owned. Maryland's population growth of a half a percent (0.5%) per year led to a loss of 79,000 acres of forest land to development between 1986 and 1999[9]. Since 1999 forest land area in Maryland has mostly stabilized with reforestation and afforestation balancing land lost to development. The state has mandated that forest cover be maintained at 40% and in many cases requires

[7] Edwards (1981)
[8] MDNR (2012)
[9] Widmann (1999)

that forest land lost to development be replaced through the Forest Preservation Act[10]. Mechanisms to foster restoration of degraded land and mitigation of pollutants in order to restore the environments capacity to produce ecosystem services are still not sufficient to ensure provision of ecosystem services. While programs do exist (the Conservation Reserve Enhancement Program, Maryland Forest Conservation Act) they do not explicitly consider ecosystem services. Many forest landowners will sell their land when it is economical, at the point where they would receive greater economic benefit from selling it for development than keeping it as silviculture or for preservation value.

Photo Credit- Stephen Badger 2016

Freshwater Wetlands in Maryland

Maryland contains 342,626 acres of freshwater wetlands, with the vast majority (>99%) classified as palustrine (meaning that they do not have flowing water). The remaining small percentage of freshwater wetlands in the state is riverine or lacustrine, meaning that they occur along with a river/stream or lake, respectively. Wetlands are defined as areas that meet two or more of the following criteria; 1. wetland hydrology (are flooded for at least a portion of the year) 2. wetland vegetation occurs or 3. hydric

[10] Maryland House Bill 706 (2013)

soils (meaning soils that have characteristics formed through flooding events). Wetlands often form at the boundary between a water body (e.g. lakes, rivers, streams, the Chesapeake Bay) and upland areas. Wetlands that occur apart from a water body are termed "isolated wetlands". For more information on wetland classifications and occurrence in Maryland see the Maryland Department of the Environment's webpage Wetlands and Waterways[11], or the US Fish and Wildlife Service's Wetlands of Maryland document[12].

Photo Credit – Sherrievon Sternberg DNR Photo Contest 2014

[11] http://mde.maryland.gov/programs/Water/WetlandsandWaterways

[12] Tiner and Burke (1995)

Coastal Wetlands in Maryland

Coastal (or estuarine) wetlands occur where land intersects saline (salt) water. In Maryland, this predominately means the Chesapeake Bay and its estuaries, although the Coastal Bays on the Atlantic coast also contain coastal wetlands. Coastal wetlands are often divided into low and high marsh, with the low marsh being inundated by daily tides and high marsh only being flooded by storm events. Coastal wetlands are typically composed of emergent vegetation, with species like cord grass (Spartina alterniflora) inhabiting the low marsh and salt marsh hay (Spartina patens) or cattail (Typha latifolia) in the irregularly flooded high marsh.

The Chesapeake Bay

The Chesapeake Bay is an incredibly productive ecosystem and is the largest estuary in the United States. It provides commercial and recreational harvests of fish, oysters, and crabs, and supports a multi-billion dollar boating industry. The Chesapeake Bay has been heavily impacted by overfishing, excess nutrient and sediment loads from agriculture and development causing anoxic dead zones, and diseases, particularly in oysters. This has led to populations of commercially important species far below historic highs. In response to this the states in the Chesapeake Bay watershed (Maryland, Virginia, Pennsylvania, Delaware, West Virginia and New York) signed the Chesapeake Bay Watershed Agreement, setting goals to improve the health of the Chesapeake Bay. The economic value of many of the ecosystem services we consider in this study, in particular the reduction of sediment and nutrient loads, is driven by the goal of improving the health of the Chesapeake Bay and its accompanying ecosystem services. The ecological functions of the Bay does sequester some carbon and nitrogen but these are fairly minor compared to the value of the commercial fishery for species such as Blue Crab, Striped Bass, and Menhaden, or the value of the industries surrounding recreation on the Bay.

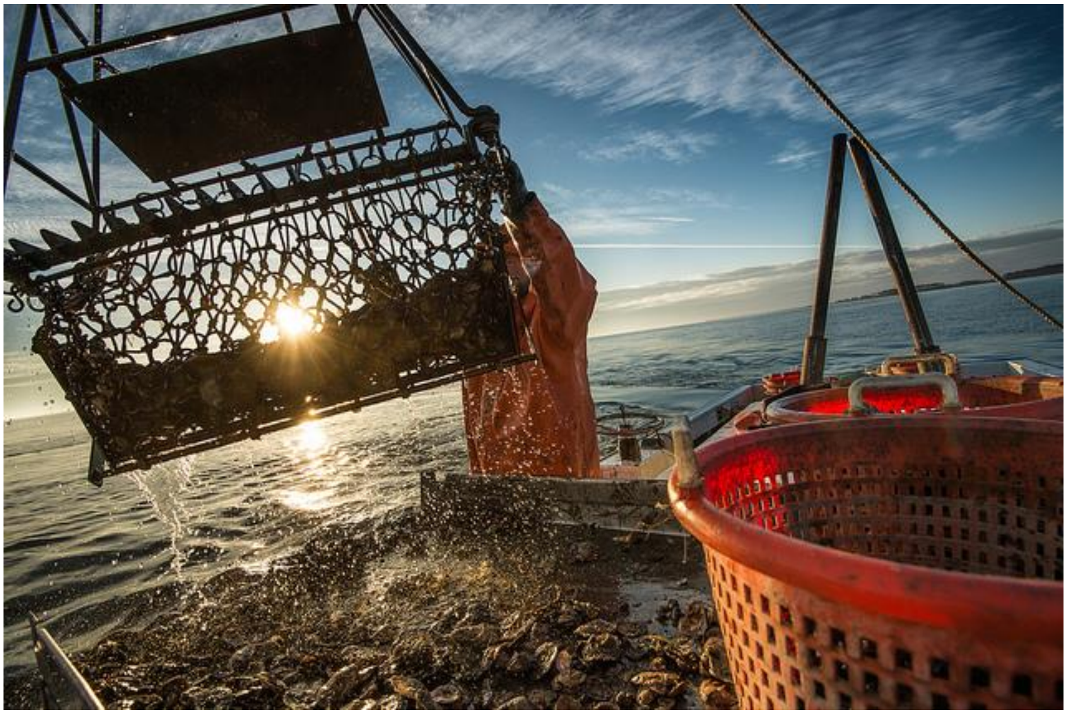


Photo Credit- William Whaley 2017 DNR Photo Contest

Maryland Land-Use

Maryland has developed rapidly in the last 40 years and is now the 5th most densely populated state. Development impacts the supply of ecosystem services, reducing the natural capital of the state. In the case of certain services, like air quality and flood prevention, an increasing population also increases the demand for the service. The first land-use map was produced in 1973 and the most recent map is from 2010[13], so we present the map of land-use in 1973 and 2010, along with totals for land-use change over this period in Figures 3 and 4. Developed land has increased dramatically over this period, by over 100%. This has come at the expense of agricultural lands (decrease of 19%) and forest land (decrease of 8.5%).

[13] Homer et al. (2015)

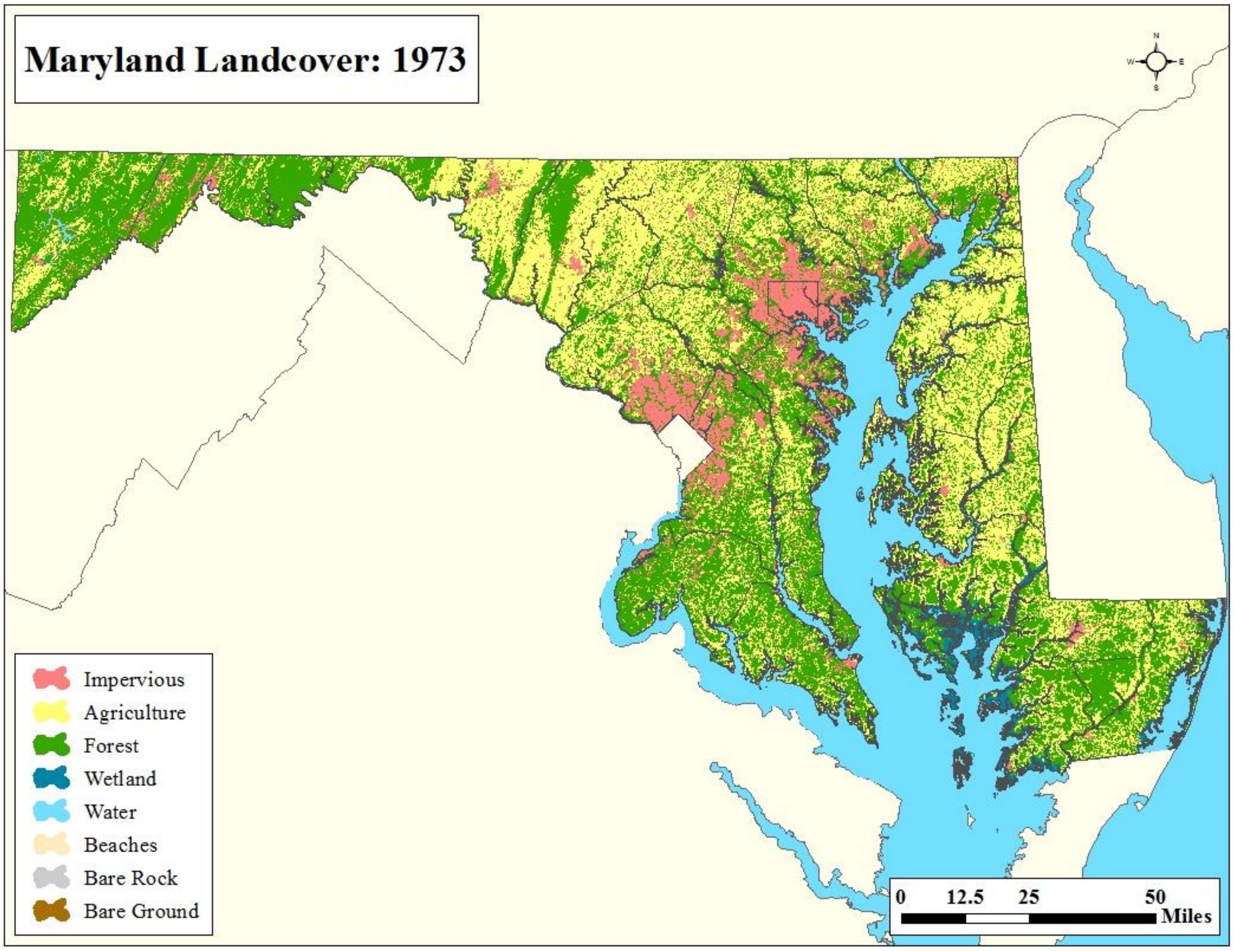
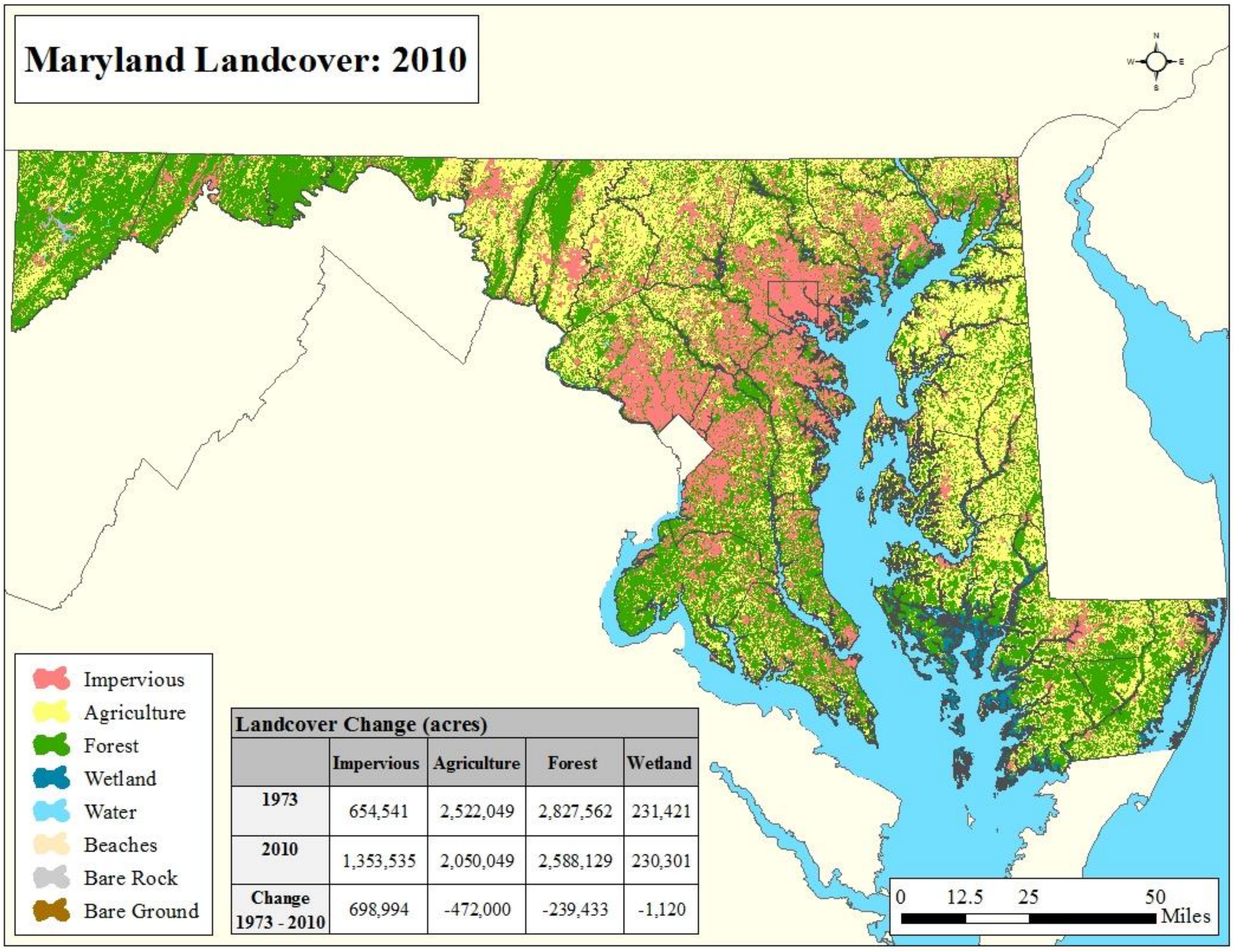


Figure 3. Maryland land-use in 1973

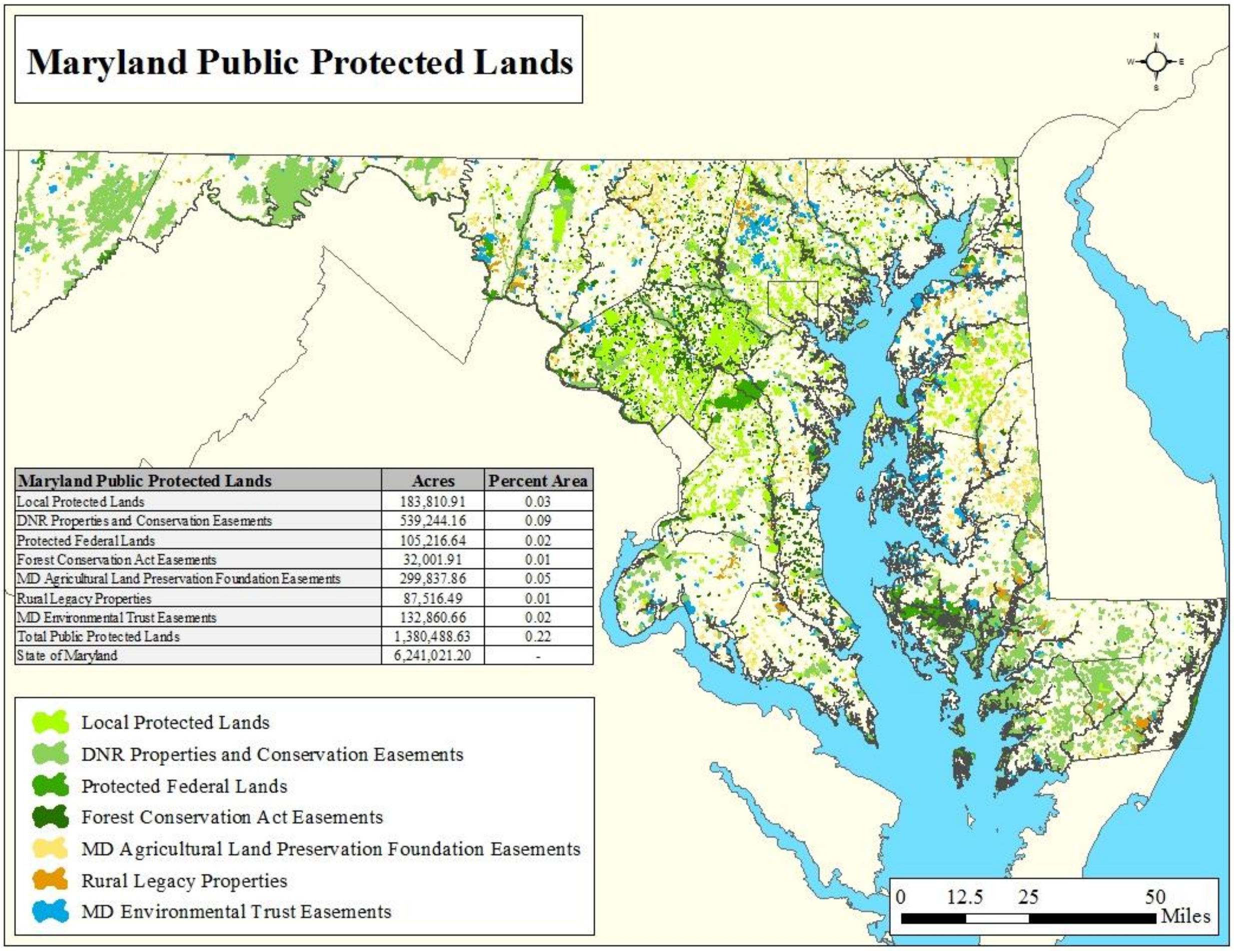


Landcover Change (acres)

	Impervious	Agriculture	Forest	Wetland
1973	654,541	2,522,049	2,827,562	231,421
2010	1,353,535	2,050,049	2,588,129	230,301
Change 1973 - 2010	698,994	-472,000	-239,433	-1,120

Figure 4. Maryland land-use in 2010

Protecting land from development through purchases by the state, local, or federal government, conservation easements, or preservation by non-profits or private citizens are all important tools in ensuring that future generations enjoy the same benefits and quality of life as previous ones. Currently lands in some form of protection total 22% of the state. State programs focusing on increasing protected lands in the state are Program Open Space along with easement programs like Maryland Environmental Trust, Rural Legacy, and Maryland Agricultural Land Preservation.



Maryland Public Protected Lands	Acres	Percent Area
Local Protected Lands	183,810.91	0.03
DNR Properties and Conservation Easements	539,244.16	0.09
Protected Federal Lands	105,216.64	0.02
Forest Conservation Act Easements	32,001.91	0.01
MD Agricultural Land Preservation Foundation Easements	299,837.86	0.05
Rural Legacy Properties	87,516.49	0.01
MD Environmental Trust Easements	132,860.66	0.02
Total Public Protected Lands	1,380,488.63	0.22
State of Maryland	6,241,021.20	-

Figure 5. Protected lands in Maryland

How We Calculate the Economic Return on Environment

If society is to preserve ecosystem services fundamental to human life, we must be able to accurately measure their ecological outputs, as well as their economic value. Even though each of these services benefits society economically, they are not all currently represented in economic markets across Maryland. While the value of provisioning and cultural services, such as fish, crabs, timber, and recreation are well understood and accounted for within our economic system, the value of regulating and supporting services, such as stormwater management and nutrient uptake, are more difficult to quantify, and thus more difficult to incorporate into an economic market. In the absence of known economic values, these services are treated as free subsidies for society (termed a positive market externality in economics). Society and individuals benefit from their existence, but are not typically held financially responsible for the management or protection of these non-market benefits.

In a market system, land use decisions are often driven by opportunity cost, favoring the most profitable option given the constraints of governmental regulation and policy. When the economic value of ecosystem services are not explicitly included in resource management decisions, there is an increased risk of natural lands being lost, which threatens ecosystem health and natural productivity, potentially impairing the well-being of current and future generations. In order to better preserve the integrity of ecosystem services provided by Maryland's natural lands, it is critical to develop mechanisms which quantify and incorporate the economic value of these services, thereby creating an additional incentive for responsible land stewardship and informing decision making by state and local governments.

Beyond their intrinsic value, natural systems provide millions of dollars of social and economic benefits every year—a triple bottom line to communities and residents. Triple bottom line refers to accounting for social and environmental costs and benefits on the same balance sheet as economic ones. Just as financial analysts express return on investments, new methods are now available to express nature's annual value to the economy in terms of Return on Environment (ROE). ROE estimates the value that people place on the work of the environment through consideration of observed financial patterns, such as costs avoided, market prices, the cost of regulations, or premiums for real estate value based on proximity to open spaces. Such estimation of economic benefits of ecosystem services to society allows policy makers, businesses and residents to view natural systems as a portfolio of financial assets rather than a commodity. Accounting for ecosystem services, and understanding the "Return on Environment" of a region, can serve the interests of conservation, the economy and society as a whole. The benefits of using an ROE valuation system are summarized in Table 2.

Table 2. Benefits of a Return on Environment valuation system

1	Nature's complex system is conveyed in a simple bottom line which is understandable to a broad audience.
2	Dollars, as a financial measure, underscore nature's connection to our quality of life, health, cost of living, economy and sense of place.
3	Dollars also convey a level of significance or priority to allow for better trade-off analysis.
4	Monetary estimates of the value of natural system services can be applied within decision frameworks related to land use, tourism and economic development.
5	Discussion of natural system cover types, services, and their values can engage key stakeholders in an educational process that can help other organizations in their missions.
6	While any numeric model will engender healthy skeptics, the discussion about nature's value finally puts this issue on the table in full view so policy makers and citizens are aware of its relative importance.

Natural systems work 24 hours a day, 365 days a year without cost to taxpayers, and may generate economic benefits for a single function or for a function that provides several services. Beyond these continuous services, like mitigating air pollution or providing wildlife habitat, nature also provides a form of insurance or risk management. Natural systems increase the resilience of an area to the effects of climate change, decreasing the risk of flooding and allowing more rapid recovery after severe weather events. In contrast to residential, commercial and industrial areas which require public or private investment for services, intact natural areas require little more than protection. Though ecosystem services are inherently renewable, the realization of continued benefits requires ecosystem productivity and biological diversity. Once ecosystem integrity is lost, these services are replaced, typically at the taxpayers' expense, or society will go without the former ecosystem services being provided. Unlike economic assets which typically recover value relatively quickly after losses, this ecologically-based portfolio of assets can take 50 to 100 years to recover its full set of services.

Through explicit economic valuation of ecosystem services and biodiversity, the relative value of protecting certain natural system services can be clearly conveyed to policy makers, investors and homeowners, highlighting ecosystem conservation as a practical long-term business strategy. It is almost always a better economic decision to conserve natural lands than restore them at a later date, as the future investments necessary to replace what is lost will likely be more expensive than employing smart growth development policy that preserves natural lands.

A number of recent studies have demonstrated that it is cost effective to invest in ecosystem services, like preserving forest buffers along a river or stream, avoiding having to remediate the water either downstream or when it is extracted for use.

- Riley (2009)[14] found that costs of riparian buffer restoration in the San Francisco Bay region of California were less than a quarter of building and maintaining a stormwater/urban runoff treatment plant to perform the same nutrient reduction function. In fact, this underestimates the difference in costs given the different time horizons of the options (the natural buffer will last in perpetuity while the treatment plant will only last ~50 years).

- Kramer et al. (2006)[15] compared forested buffers near Wisconsin lakes with septic upgrades for reducing nutrient loading to the lakes. In the 25 instances studied the forested buffer was found to be the more affordable option for nutrient reduction in all but one case.

- Keystone Conservation Trust evaluated ecosystem service benefits in 5 Pennsylvania counties[16], finding that for every dollar invested in conservation seven dollars of ecosystem service value is returned. These findings influenced the Northhampton Co. (Pennsylvania) Commissioners in increasing their open space budget by $2.2 million for fiscal year 2016.

- New York City invested $1.5 billion in land preservation in the watershed of their drinking water source, ensuring the high quality of their drinking water. This investment avoided having to build a $10 billion water treatment plant[17].

[14] Riley (2009)
[15] Kramer et al. (2006)
[16] Lehigh Valley Planning Commission (2014)
[17] New York State Department of Environmental Conservation (2015)

Biophysical and Economic Value

All ecosystem services, defined here as ecological work which benefits human well-being, termed "final ecosystem services" by Boyd and Banzhaf,[18] have two dimensions — biophysical value and economic value. Biophysical (biotic and abiotic components of the environment) value is the actual quantity of the ecological function that is yielding an economic benefit, e.g. grams of carbon being sequestered, cubic meters of water being recharged to the aquifer, etc.. The biophysical value is equivalent to the Benefit Relevant Indicator in the suggested ecosystem service model for the US federal agencies[19]. Economic value is the difference between the price paid for a good and what a consumer would be willing to pay **-** i.e. the consumer surplus. However, this information is not easily obtained for ecosystem services. Often one dimension may have been assessed, such as what a consumer would be willing to pay through contingent valuation or what a consumer has paid through a travel cost analysis; but it is very rare for a study to have assessed both dimensions, so that an economic value can be determined. This is why the monetary output of these assessments is expressed in terms of economic preference rather than economic value. In the approach presented in this work both biophysical and economic quantifications are essential in performing an economic analysis of ecosystem services. A biophysical quantity without a connection to a consumer is not a service, and a person without access to a quantity of ecological work cannot consume it, these factors are considered along with the fact that the demand function of the consumer will change with the biophysical supply. For example, a wetland in the Canadian boreal forest is taking up nitrogen and phosphorus, but this is not an ecosystem service if there is not a population being impacted by impaired conditions in downstream waterbodies. While it is difficult to imagine a situation where a consumer has no access to any ecosystem services, beyond situations unconducive for human life like space travel, there are many situations where biophysical supply is constrained and demand increases, such as during drought conditions in the American southwest where water supplies are limited.

Types of Economic Value

The type of value we most often consider is ***market value,*** which is the price of a good or service in a market. From the market price economists calculate ***consumer surplus***, the difference between what someone paid for a good or service and the most they would have been willing to pay. However, for most

[18] Boyd and Banzhaf (2007)
[19] Olander, et al. (2015)

ecosystem services a market does not exist. Many different ***non-market valuation*** methods have been proposed. They range from asking a sample of people what they would pay for an ecosystem service (***contingent valuation***) to using the price of proximal homes to estimate the value people place on being near natural areas (***hedonic pricing****)*, evaluating what it costs to visit a natural area (***travel cost analysis****)*. However, all of these methods have well known flaws. For example, contingent valuation is subject to hypothetical bias, meaning that people are likely to over-or-understate what they would actually pay for something. Hedonic pricing and travel cost analyses do not actually measure the ecosystem service (ES) and can easily conflate benefits from the ecosystem with other values. These methods are typically biased towards measuring immediate economic well-being, discounting longer term values, such as intergenerational equity.

Social Value measures the benefit of something not just at the level of the individual (i.e. someone's willingness to pay for a good or service), but the benefit to a group of people. This type of valuation is particularly appropriate for valuing ecosystem services, as very often benefit the public as a whole (i.e. a ***public value***) and do not have traditional markets. This analysis calculates the social value of ecosystem services, where society overall is benefiting from the work of the environment. It is important to note that while social value is an inclusive measure of the benefits that the public gain from the work of the environment, it is not the same as market or compensatory value, and the values presented here are not meant for that purpose. Social value is intended to be used to inform decision making and trade-offs, rather than market exchanges.

ACCOUNTING FOR MARYLAND'S ECOSYSTEM SERVICES (AMES)

To address the need for better economic valuation of the ecosystem services provided by Maryland's natural resources, the **Chesapeake and Coastal Service's Center for Economic and Social Sciences** has developed a spatial modeling framework, **"Accounting for Maryland's Ecosystem Services"** (AMES). The goal of the AMES model framework is two-fold – 1) to quantify the biophysical value of ecological work spatially across the state and 2) to estimate the economic value, or eco-price, of this work. We rely upon existing spatial maps of the biophysical supply of ecosystem services (i.e. metric tons (mt) of carbon sequestered, cubic meters (m^3) of groundwater recharge, etc.) from federal and state agencies (see proceeding sections for specific data sources), The model outputs a series of spatially explicit maps, which capture variation in the biophysical and economic value of individual ecosystem services performed in forest and wetland areas, as well as the total value of all co-occurring ecosystem services across the state of Maryland. AMES currently incorporates seven ecosystem services: **carbon sequestration, wildlife habitat and biodiversity, storm water mitigation, groundwater recharge, surface water protection, nutrient uptake** and **agricultural benefits**. Figure 6 illustrates the AMES model framework.

We determined the ecosystem services to be considered in this work to be ecological functions that positively impact human well-being, i.e. the ability to meet basic human needs and satisfaction, or avoid a decrease in well-being, i.e., as measured by a change in final ecosystem goods and services, which are not already being valued in a market or proxy market (e.g. timber and recreation, respectively). The market eco-prices we do consider (e.g., for carbon and water) have been either induced by regulation (i.e., carbon) or regulated by government (i.e., water supplied from a public utility). The services that remain are those suitable for evaluation through the eco-price method. The method has the following steps:

1. Quantify the biophysical flow in the studied ecosystem. Ideally this would be done with field measurements or a simulation model of the particular system to be evaluated, but lacking these measures literature values for the studied system could be substituted.

2. Calculate relevant eco-prices for ecological work performed in the system under study; categorize the eco-prices based on the type of environmental product (i.e. water, soil, carbon, etc.).

3. Calculate the ecosystem value for each category by applying equations 1-3 (see pages 21-22).

4. Sum individual ecosystem service values to find the total economic value of the ecosystem services provided by the system.

Forest and wetland areas across Maryland were identified using a combination of two datasets: NASA LiDAR for tree canopy cover[20] and a unification of the National Wetland Inventory[21] and DNR wetland inventory[22]. The biophysical value of individual ecosystem services within these forest and wetland areas was then quantified using a set of unique ecological sub-models. For some services, the AMES framework leverages the power of existing external ecological models, while other services are modeled internally using a combination of GIS data inputs and published ecological thresholds. Each sub-model produces a per-pixel (30 m) estimate of the amount of biophysical output produced by a given service across the state.

[20] Hurtt (2016)

[21] US Fish and Wildlife Service (2016)

[22] Maryland Department of Natural Resources (1995)

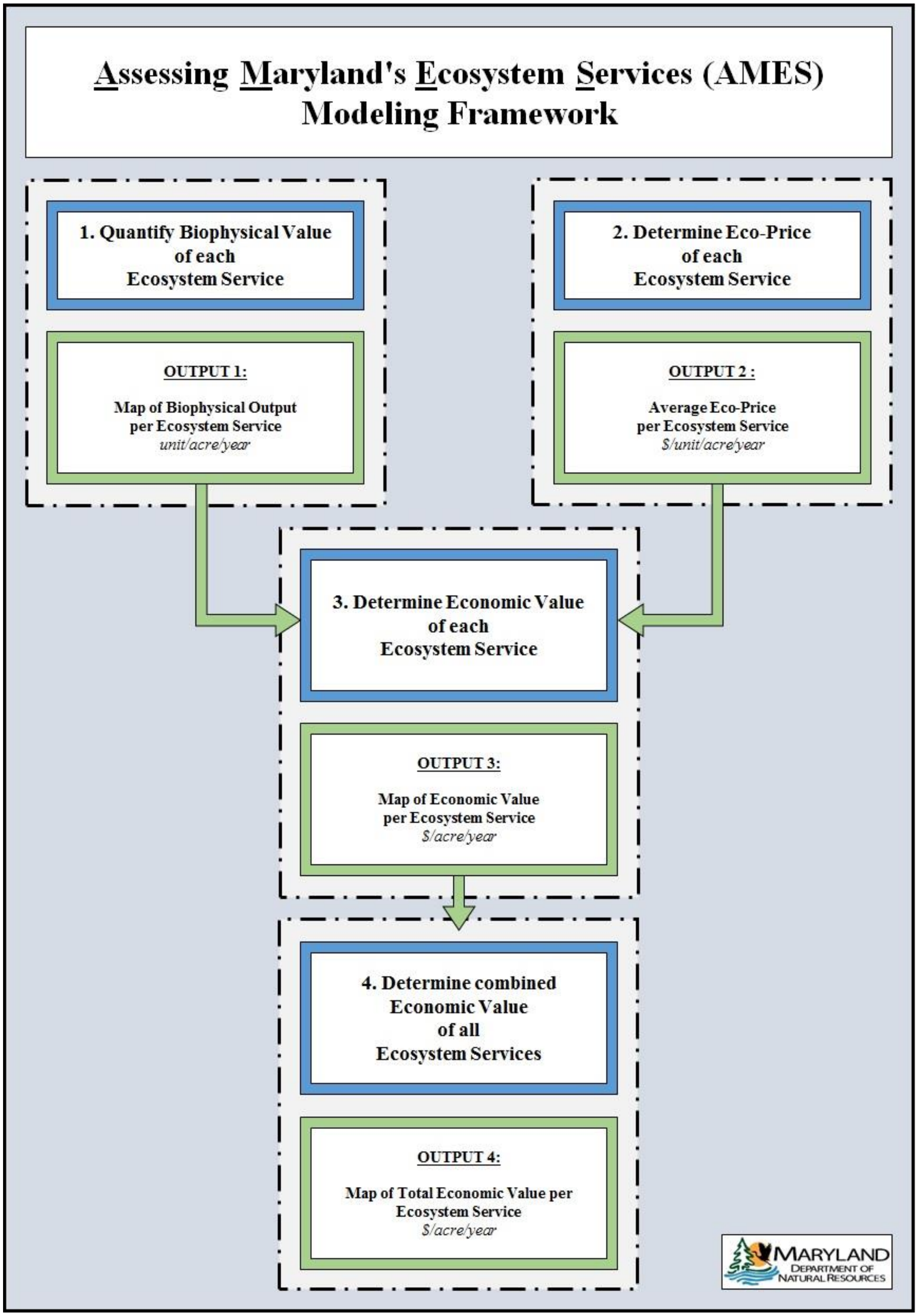


Figure 6. AMES model framework

Pricing the Environment: The "Eco-Price"

One mechanism which has been developed to put a social economic value on the work performed by the environment is the **eco-price**. The eco-price is defined as the ratio of dollar amount that has been paid to preserve or restore ecosystem services, or cost avoided, to the change in ecological function, where dollar amounts based on current trends in society's payment for and valuation of these services[23,24]. Again, this is necessary because these services largely exist outside of traditional markets. The eco-price reconciles the biophysical value of the environment with economic value and extends the capability to suggest monetary values for the work of the environment to be used when evaluating management alternatives, ecosystem service markets, or formulating policy. The value generated through the eco-price is not the same as market value and is not meant to imply landowner compensation for services provided.

As an example of the utility of the eco-price, consider nutrient management activities carried out by a private land owner in Maryland. This private landowner can plant a riparian forest buffer on their land that will take up a certain estimated amount of nitrogen. This quantity of nitrogen could then be sold on the MD nutrient marketplace to municipalities needing to meet their mandated water quality goals for a certain dollar amount. Another example is payment made for reducing nitrogen loads to the Chesapeake Bay through the Maryland Bay Restoration Fund, where water users pay a fee used to retro-fit water treatment plants in the state, and through installation of best management practices for nutrient reduction (riparian buffers, wetland restoration, etc.) in the watershed. The amount paid per pound of nitrogen is calculated for each instance of society investing in nutrient reduction, and then averaged in order to estimate how society values nitrogen reduction, overall.

Depending on the way society is paying for ecological work the eco-price can be formulated as:

Equation 1. Change in biophysical service / Change in Market Eco-Price = marginal increase in ecosystem service, units are biophysical quantity of service / cost of generating the marginal increase, in $

[23] Campbell and Tilley (2014a)
[24] Campbell and Tilley (2014b)

Equation 2. Avoidance Eco-Price= ecosystem load avoided, units are biophysical quantity of the load / cost of avoiding the ecosystem load, in $

Equation 3. Replacement/Damages Eco-Price = ecosystem service lost, units are biophysical quantity of service / cost of replacing the service, in $

The economic value of each ecosystem services was derived from the work of Campbell[25] which analyzed 60 instances in which money has been exchanged for the work of the environment. These instances spanned a range of payment types, including regulatory programs (e.g. Maryland's Bay restoration fee, stormwater management fee), NGO investments (e.g. purchases by the Conservation Fund, Ducks Unlimited), market exchange (e.g. Regional Greenhouse Gas Initiative purchases, nutrient trading in Pennsylvania), or tax incentives (e.g. benefit of enrolling land in conservation programs). Because society places differing values on different ecosystem services, observed dollar amounts paid were categorized by relevant ecosystem service. For each service, an average was calculated for each payment type. For each individual service, the mapped biophysical output values were then multiplied by the average eco-price, to produce per-pixel estimates of the eco-price of each service across the state of Maryland. Finally, per-pixel eco-prices for each individual service were summed, to produce an estimate of the economic value of all ecosystem services occurring in a given area.

The following section outlines the data and models used to assess each ecosystem service, as well as an estimate of the spatial distribution and economic value of these services across Maryland. The map of the spatial distribution of each ecosystem service also contains a table summarizing the annual economic value of the service, the minimum value, the maximum value, the average value, and the acreage in the state that was included. The appendix to this document details the procedures used in ArcGIS.

[25] Campbell (2017)

Results for Maryland's Ecosystem Service Assessment

Carbon Sequestration

Carbon dioxide (CO_2) is a naturally occurring greenhouse gas (GHG) found in the Earth's atmosphere which plays a critical role in maintaining a climate suitable for life on this planet. Though beneficial to life, rising atmospheric concentrations of CO_2 over the past century have been linked to increases in climate variability and change at local, regional, and global scales. Over the past 30 years, climate researchers have worked to quantify the flux of carbon between sources and sinks in the carbon cycle. Forested areas have been identified as one of the major carbon sinks existing on Earth. During the process of photosynthesis, trees remove CO_2 from the atmosphere, releasing oxygen (O_2) and converting carbon (C) to long term storage within the woody biomass of their trunks. Thus, the world's forests hold an immense amount of carbon in standing trees, and have the potential to continue sequestering carbon as they grow. Wetlands also have a large capacity for sequestering carbon, particularly coastal wetlands which have high primary production and produce less methane (a gas which contributes to warming), than freshwater wetlands.

In 2009, The Maryland Green House Gas Emissions Reduction Act (GGRA) was signed into law, requiring the state to reduce statewide GHG emissions by a minimum of 25% by 2020. In 2016 it was updated and a new goal was set of reducing emissions 40% by 2030. Expansion of forested area is one of the most straightforward and economical ways to mitigate CO_2 emissions and combat global change. Increasing forested area across the state could thus play a significant role in meeting state implemented GHG reduction goals.

Quantifying Carbon Sequestration across the Landscape

Forest extent across Maryland was delineated using the Lidar-derived Percent Tree Canopy, which identifies tree cover at a 30 m resolution and the NLCD Land-use/Land Cover dataset only for the portion not mapped using LiDAR over the Aberdeen Proving Ground military base (see appendix for method used). The rate and amount of carbon sequestration within forests and wetlands varies spatially across Maryland. The primary sources of variation in forested areas is tree age and species composition, with deciduous trees such as oaks and hickories sequestering more carbon than do evergreen trees such as pines and hemlocks. Carbon sequestration rates for hardwoods (deciduous), softwoods (evergreen), mixed forest, and shrubland were taken from the USFS i-tree landscape online tool[26] and ranged from 0.4 Mt per ha to 3 Mt per ha, excepting outlier values. Wetland extent was delineated using a DNR wetlands dataset, which identifies wetland areas as freshwater palustrine forested, emergent, and estuarine. Across wetland areas, forested wetlands (swamps) and coastal wetlands tend to sequester higher amounts of carbon than do freshwater wetlands with emergent vegetation. However, fresh and brackish wetlands also emit methane, a greenhouse gas. These emissions have a global warming potential greater than the carbon sequestered for freshwater wetlands, decreasing as the salinity of the water increases. Above a salinity of 18 methane emissions are negligible (see Table 4). Average sequestration rates for each wetland type were determined based on scientific literature[27]. Average sequestration rates for each forest and cover type were applied to calculated yearly carbon sequestration potential per unit area across the landscape. Sequestration rates for both forest and wetland areas are summarized in Table 3.

Table 3. Carbon sequestration rates by salinity class

Wetland System	N Sites	Mean C Rate (g/m2/yr)	Mean C Rate (MT/ha/yr)	Deviation
Estuarine				
Fresh	30	391.72	3.92	2.46
Oligohaline	15	293.01	2.93	1.47
Mesohaline	47	206.70	2.07	0.61
Palustrine				
Emergent	11	333.41	3.33	1.87
Forested	18	106.15	1.06	-0.40
Verificed Carbon Standard (VCS) Average[28]			1.46	

[26] USDA Forest Service (2016)

[27] Versar (2003)

[28] Restore America's Estuaries (2016)

Table 4. Methane emission rates by salinity class

Salinity Class	***N Sites***	***Mean*** *($MT\ ha^{-1}yr^{-1}$)*	***CO2 equiv*** *($MT\ ha^{-1}yr^{-1}$)*	***C equiv*** *($MT\ ha^{-1}yr^{-1}$)*	***C equiv*** *($g\ m^{-2}yr^{-1}$)*
Tidal Freshwater *(<0.5 ppt)*	*9*	*0.8203*	*20.5083*	*5.5881*	*558.81*
Oligohaline *(0.5 - 5.0 ppt)*	*6*	*0.4568*	*11.4208*	*3.1119*	*311.19*
Mesohaline *(5.0 - 18.0 ppt)*	*13*	*0.192*	*4.8*	*1.3079*	*130.79*
Polyhaline *(> 18 ppt)*	*6*	*0.0085*	*0.2125*	*0.0579*	*5.79*

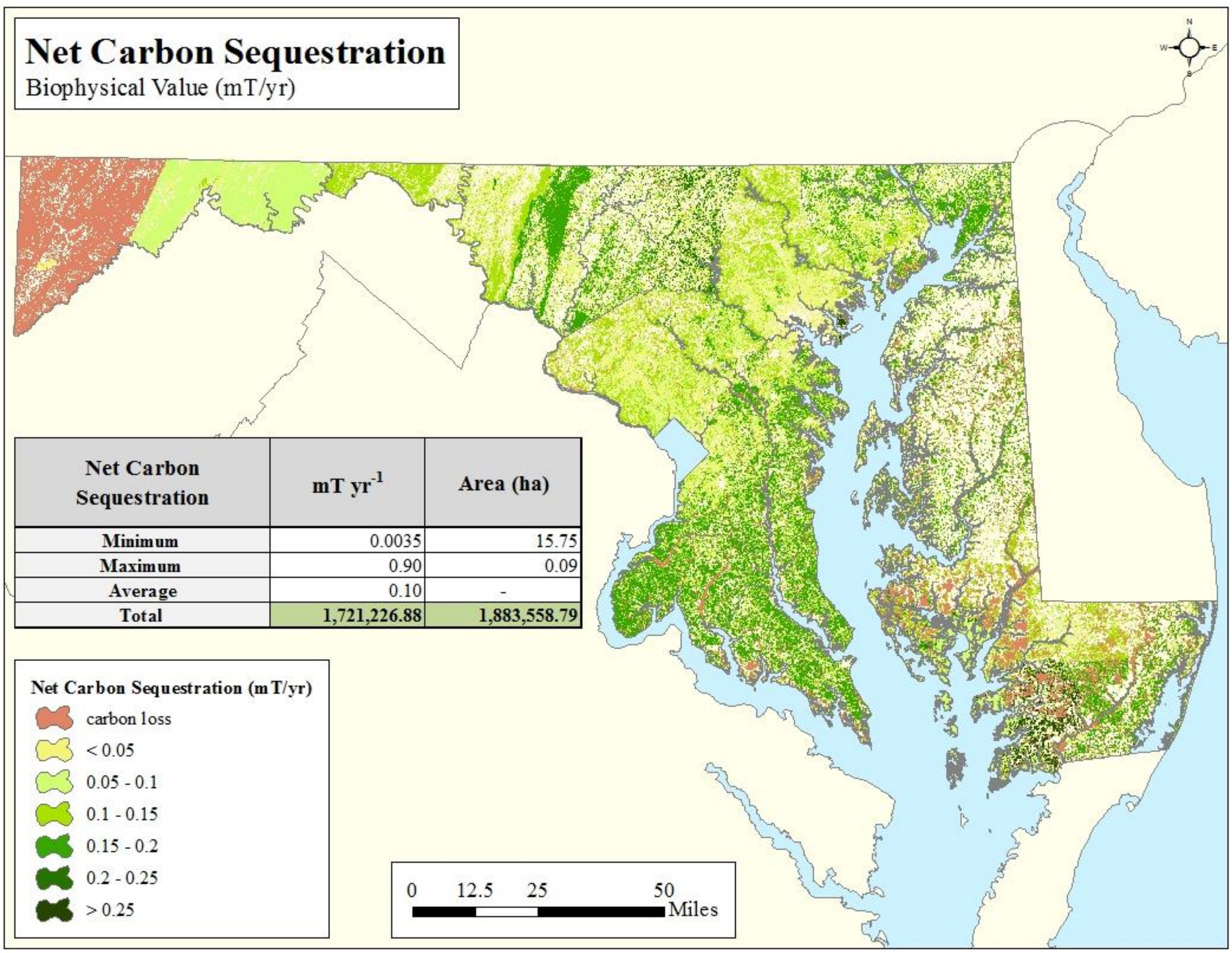


Figure 7. Carbon sequestration in forests and wetlands across Maryland

Valuing Carbon Sequestration

We use the Social Cost of Carbon[29] calculation (an estimate of the costs of climate change), the federal standard established by the US EPA, to value carbon sequestration in Maryland. We use $143 per mt of carbon, the mid-point of the Social Cost of Carbon, in this work. This ecosystem service totals $233.7 million for the state, figure 9 displays totals for each county and carbon sequestration per acre by county.

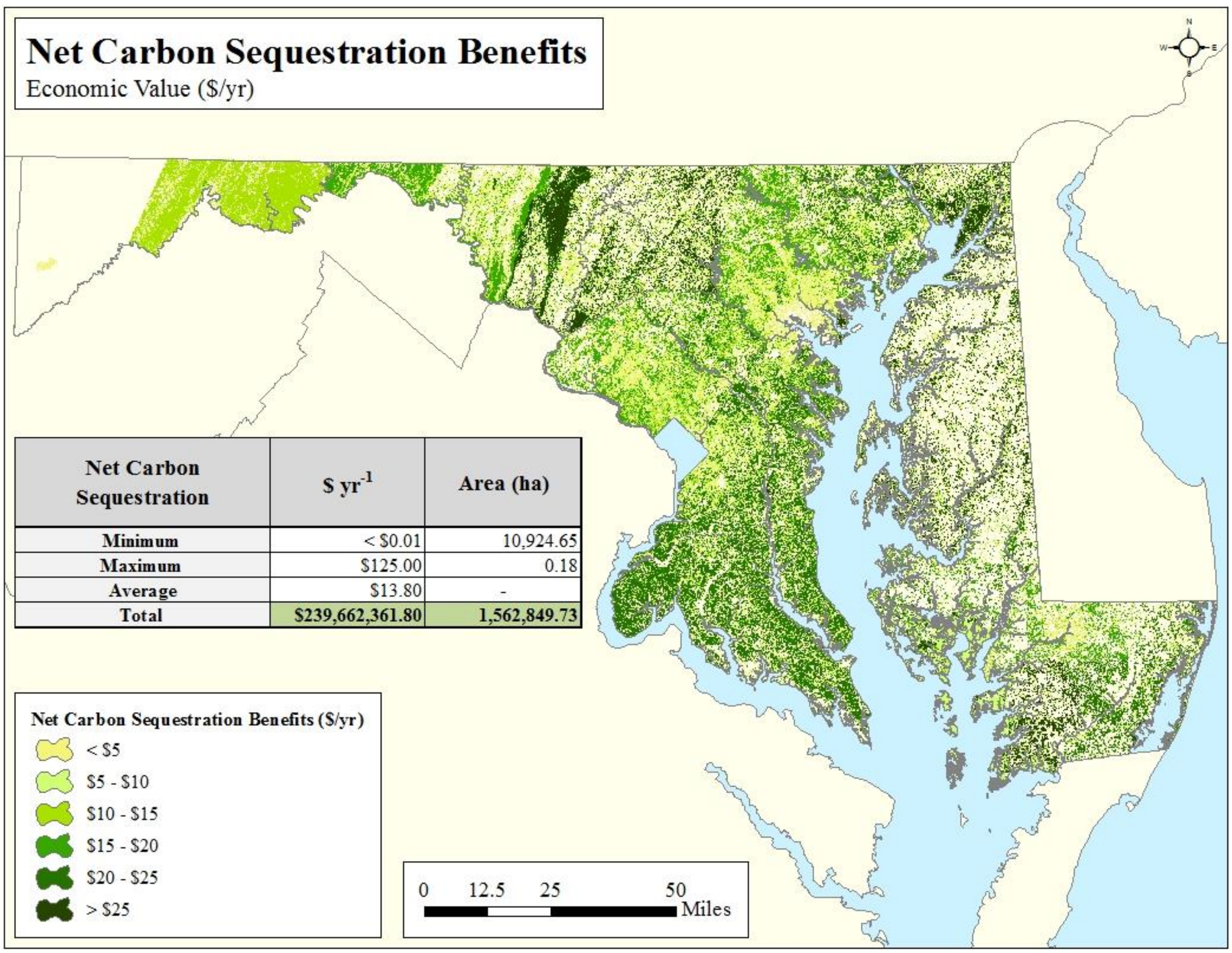
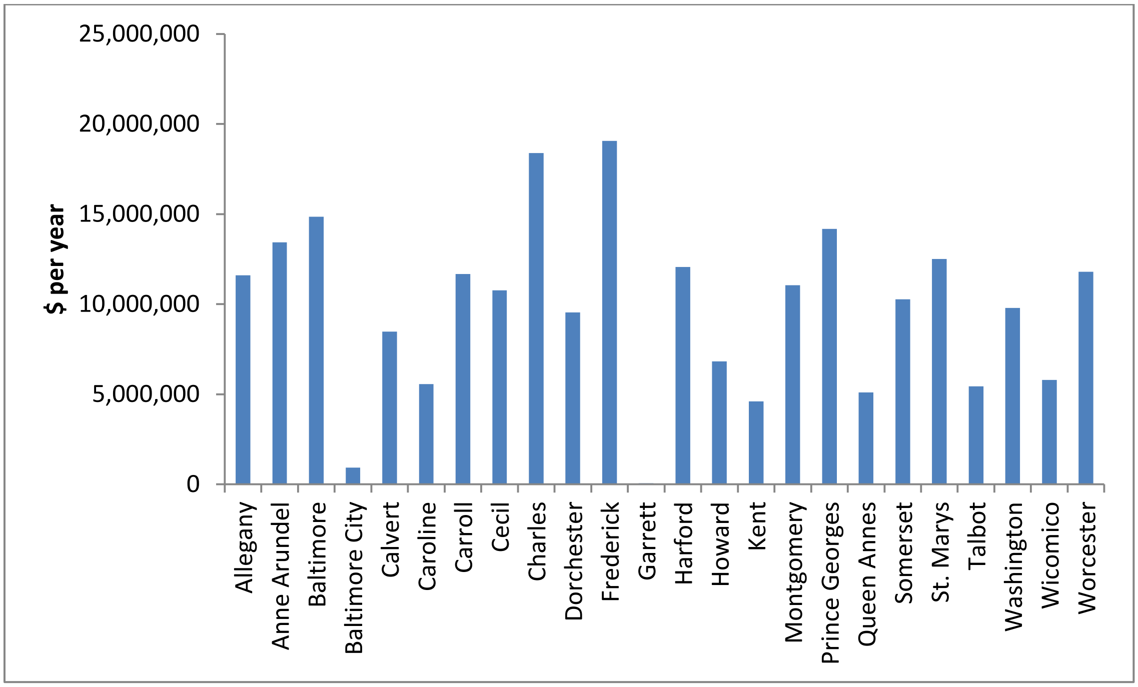


Figure 8. Economic value of carbon sequestration by forests and wetlands in Maryland

[29] Interagency Working Group on Social Cost of Carbon (2013)

County Comparison



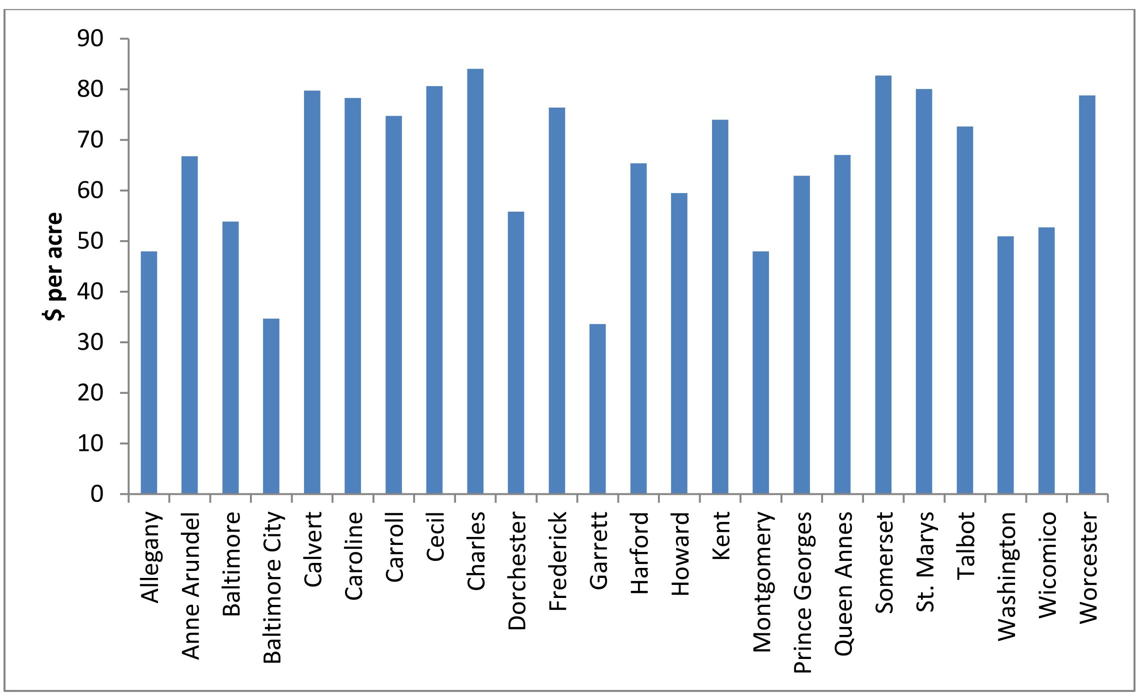


Figure 9. a) Sum of carbon sequestration ecosystem service by county b) average value of carbon sequestration per acre by county

Wildlife Habitat and Biodiversity

Forests in Maryland support a variety of plants and animals. Some of which are important for hunting such as deer, turkey, or bear and others that are rare or endemic species like the Delmarva Fox Squirrel (*Sciurus niger cinereus*) or Short Eared Owl (*Asio flammeus*). A healthy, biologically diverse ecosystem is essential to providing habitat for wildlife, and ultimately, through maintaining the ability of the ecosystem to function, all of the other ecosystem services being provided by natural lands. Without the linkages and interactions that different species convey to the system many of the ecosystem services considered would be lessened, or not exist at all. For example, a diverse system is key to developing healthy soils, which in turn supports a higher capacity to recharge groundwater, store water on the landscape to reduce runoff, and store carbon.

Quantifying Wildlife Habitat and Biodiversity across the Landscape

We looked at the size of habitat, degree of connection to other habitats (scored through the MD Green Infrastructure model)[30], and presence of rare species or habitats (scored through the MD BioNet model)[31]. Land in the top two ranks of MD BioNet was assigned the 1st and 2nd quintile of value, respectively. Land in the Green Infrastructure was assigned into quintiles based upon their score, and assigned corresponding values. Forests and wetlands occurring outside both models were given the lowest quintile value. Figure 10 displays the Wildlife Habitat and Biodiversity Index across Maryland.

[30] Weber (2003)

[31] MD DNR (2016)

Photo Credit Susan Burkholder DNR Photo Contest 2015

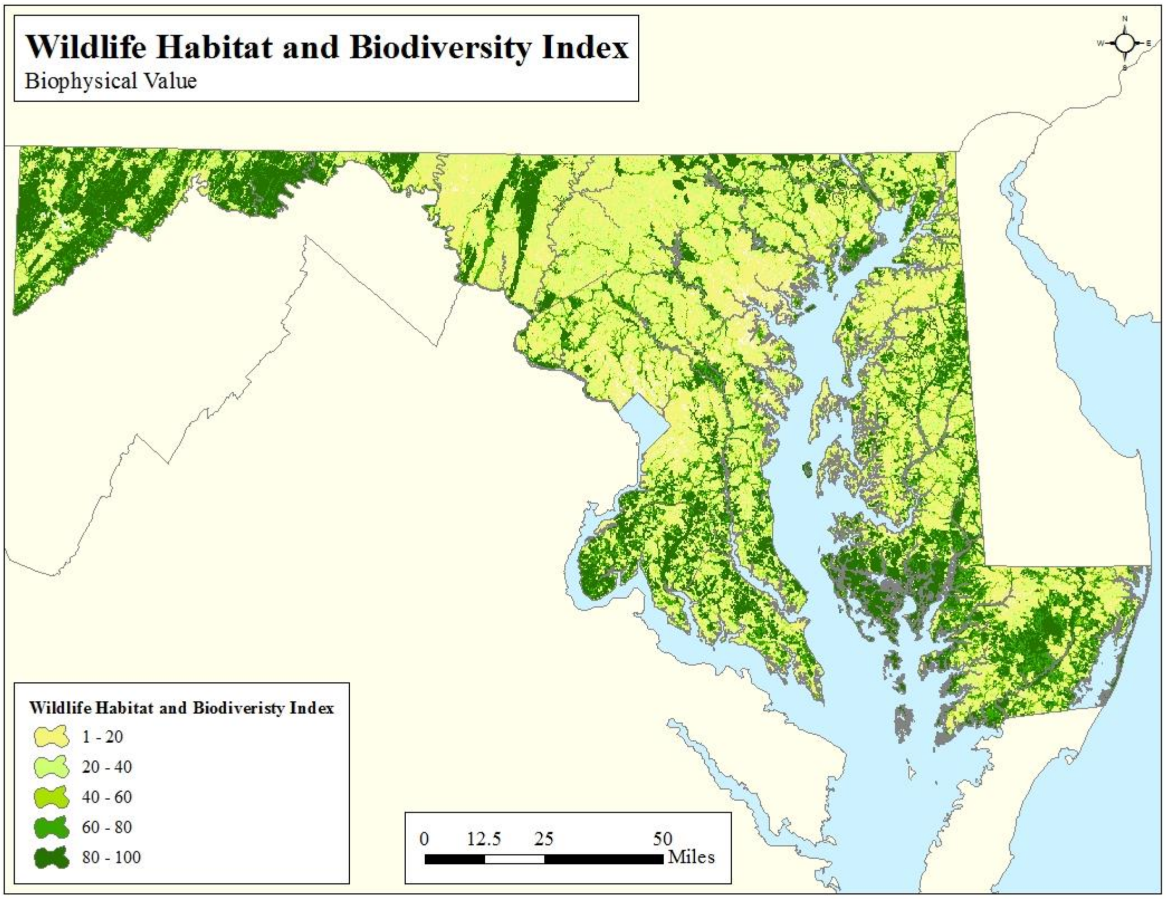


Figure 10. Wildlife Habitat and Biodiversity Index across Maryland

Valuing Wildlife Habitat and Biodiversity

Cost to preserve natural land (i.e. investments made by Ducks Unlimited, Conservation Fund, habitat banking)[32,33,34,35,36], annualized over 15 years, period that tax benefit can be spread. This averages $1023 per acre of natural land. Instances of payment used to calculate the average eco-price of wildlife habitat and biodiversity are summarized in Table along with the estimated tax benefit. The value of habitat for rare and threatened species as characterized by price paid for habitat banking or was assumed to be the

[32] USDA NRCS (2009)
[33] Ducks Unlimited (2014)
[34] Conservation Fund (2014)
[35] The Baybank (2012)
[36] MD DNR (2016)

maximum value, assigned to Tier 1 and 2 of BioNet and the 100 values of the Green Infrastructure score, scaling linearly with the GI score in all areas outside of BioNet tier 1 and 2 (e.g. an area with a GI score of 50 would be assigned an economic value of 0.5 * $283 per 30 m pixel = $141).

The spatial distribution of the economic value associated with wildlife habitat and biodiversity across Maryland is illustrated in 11. This service totals $2.6 billion for Maryland every year, the second highest total found for ecosystem services considered in this study.

Table 4. Eco-prices used to calculate the biodiversity and wildlife habitat ecosystem service value

Biophysical Category and Measure	Eco-Price	Units	Exchange Classification
Wetland Reserve Program	$1,125	$/acre	Investment
Ducks Unlimited	$1,223	$/acre	Investment
Mid-Atlantic Conservation Fund	$1,726	$/acre	Investment
Habitat banking: Trout Conservation average	$3,499	$/acre	Cost of Regulation
Habitat banking: Delmarva Fox Squirrel Habitat	$5,748	$/acre	Cost of Regulation
Habitat Banking: Puritan Tiger Beetle	$6,025	$/acre	Cost of Regulation
Tax Benefit Conservation Enrollment in MD	$933	$/acre/yr	Tax benefit
Average Yearly Benefit (15 year time horizon, yearly tax benefit)	$1,023	$/acre/yr	•
High Estimate (Tax benefit + Habitat Banking)	$1,282	$/acre/yr	•

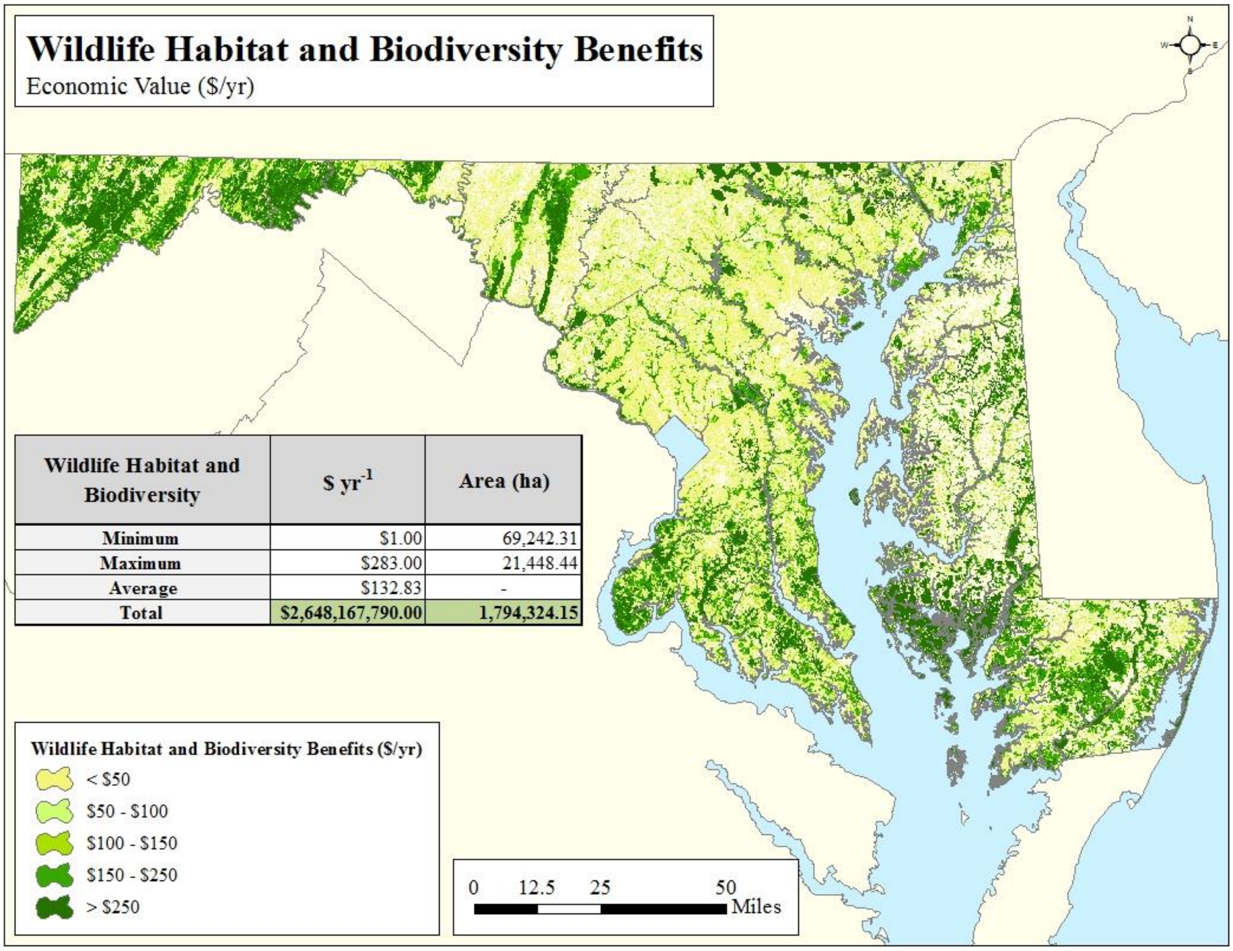


Figure 11. Economic value of wildlife habitat and biodiversity across Maryland

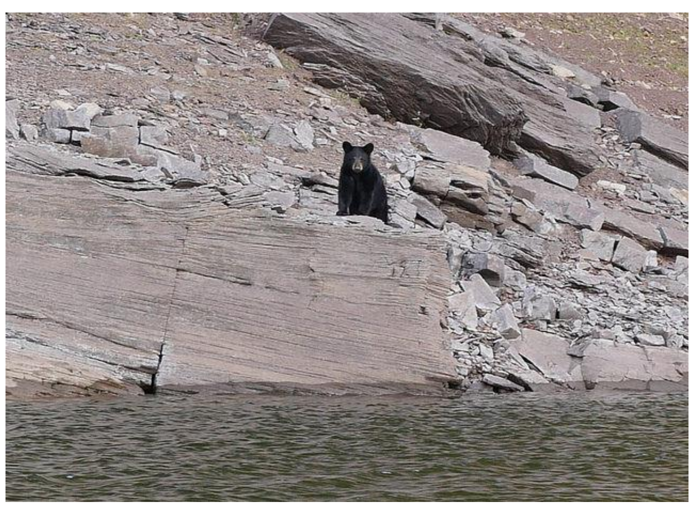
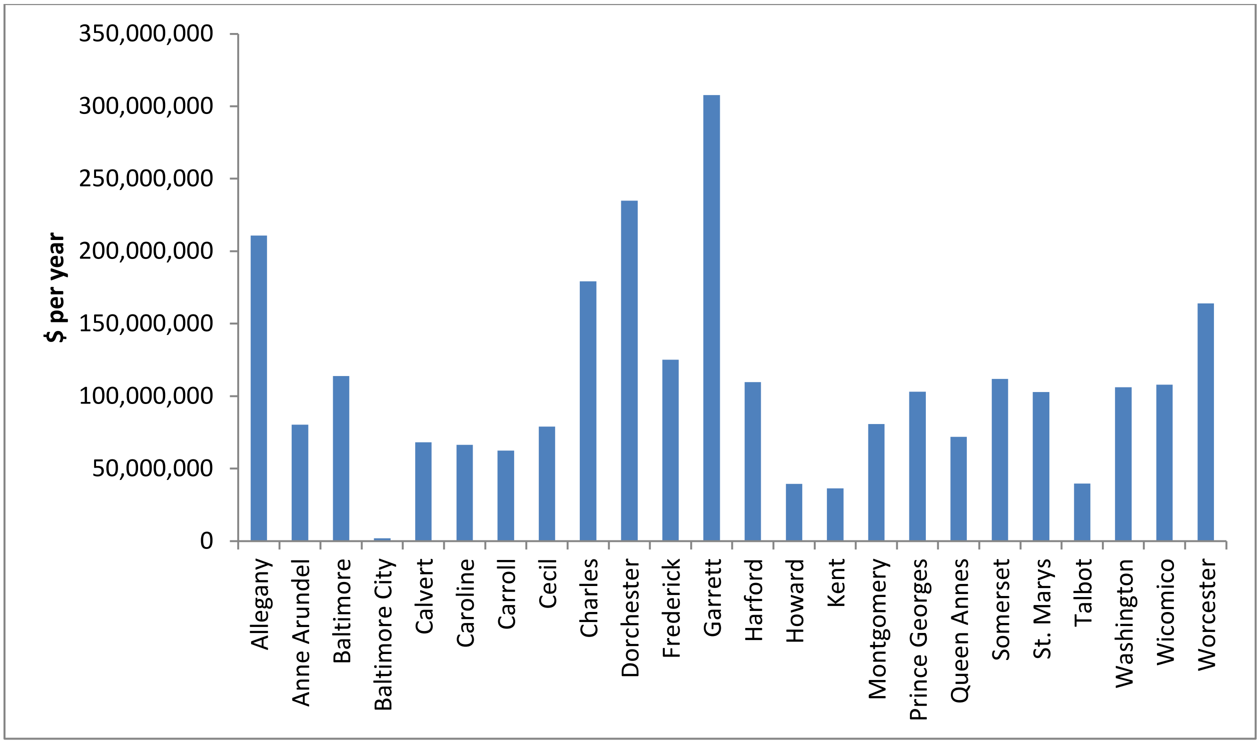


Photo Credit- Stephen Badger 2016

County Comparison



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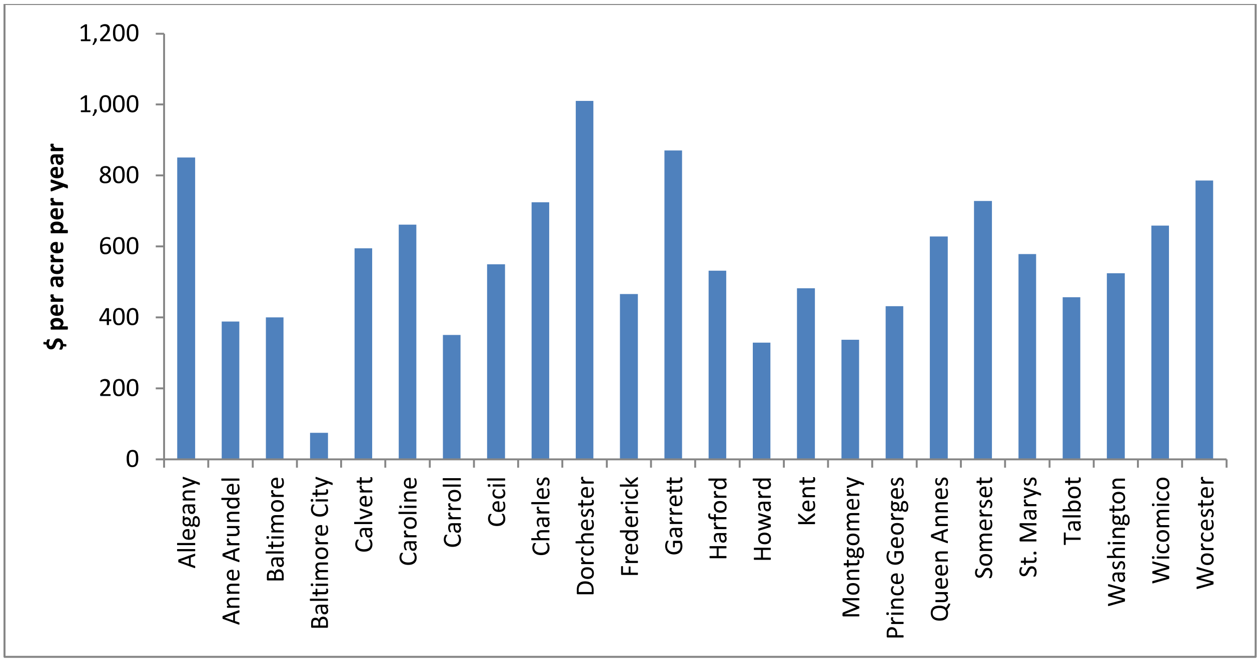


b)

Figure 12. a) Sum of wildlife habitat/biodiversity ecosystem service by county b) average value per acre by county

Air Pollutant Removal

The forests of Maryland play an important role in reducing air pollution in the state. Trees remove pollutants from the air by absorption through leaf stomata and interception by leaves. The forest soil is also a large and important sink for air pollutants like carbon monoxide. This ecosystem service is especially important due to its effect on human health. The pollutants removed from the air by trees can have many negative effects on human health, causing or exacerbating bronchitis, cardiovascular stress, and asthma. A study led by David Nowak of the US Forest Service (USFS)[37] found that forests remove over 17 million tons of air pollutants in the United States, avoiding nearly $7 billion in air pollutant caused medical costs.

[37] Nowak et al. (2014)

Air Pollutant Removal across the Landscape

Trees remove more air pollutants with a greater impact on human health in urban areas. The study done by the USFS looked at the reduction of both human mortality and respiratory ailments due to fewer air pollutants, finding the effect was much more pronounced in urban areas than rural ones, due to the combination of there being more people to benefit and worse air pollution in urban areas. This information is available for the continental United States through the i-tree landscape tool. This study combined modelling of the removal of air pollutants by trees (see figure 13) and what would be the resulting health costs of the removed pollutants (accomplished through the US EPA's BenMap model[38]). Urban areas are defined as having a population density greater than 2,500 people in the census area.

Photo Credit- Tawes State Office Building, Stephen Badger 2014

[38] US EPA (2012)

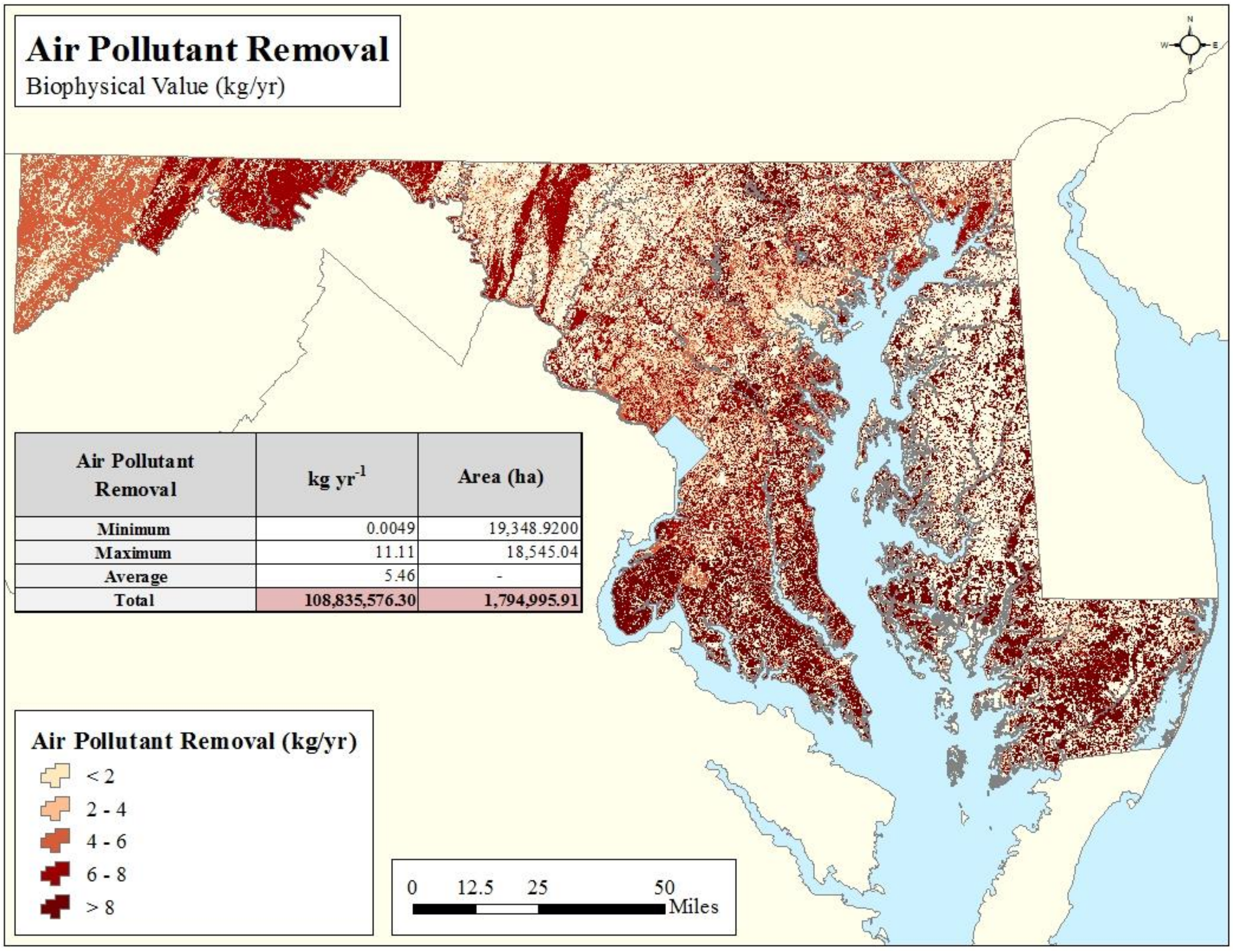


Figure 13. Mass of air pollutants (sum of the six considered here) removed by tree canopy across Maryland

Valuing Air Pollutant Removal

We use the economic impact that tree air pollution removal has on health costs. The air pollutants taken up by trees would otherwise cause health ailments in the populace at a certain known rate, with a certain known cost. The removal rates by trees and the resulting economic benefit of reducing air pollution has been quantified by the US Forest Service and made available through the i-Tree Landscape tool[39]. Removal rates and values of air pollutants are summarized in Table 5.

[39] USDA Forest Service (2016)

The spatial distribution of air pollution removal and associated economic values across Maryland is illustrated in figure 14. This service totals $140 million per year for Maryland, with the highest values for counties in the Baltimore-Washington corridor (Prince George's, Montgomery, Anne Arundel, and Baltimore), along with Baltimore City.

Table 5. Eco-prices used to calculate the air pollution removal ecosystem service value

	Pollutant Removal (kg / yr)	Value ($ / yr , m2)	Eco-Price ($ / kg)
CO	1,479,582.57	$593,939.18	$0.40
NO2	11,037,156.64	$1,235,843.50	$0.11
O3	72,442,391.97	$42,872,606.88	$0.59
PM25	2,867,290.05	$83,937,759.78	$29.27
SO2	4,663,672.71	$122,014.09	$0.03
PM10	16,142,334.66	$20,466,421.98	$1.27
Total	**108,632,429.56**	**$149,228,585.17**	**$1.37**
Area (m2)	25,630,890,300.00	-	-
Canopy (m2)	12,520,784,221.45	-	-

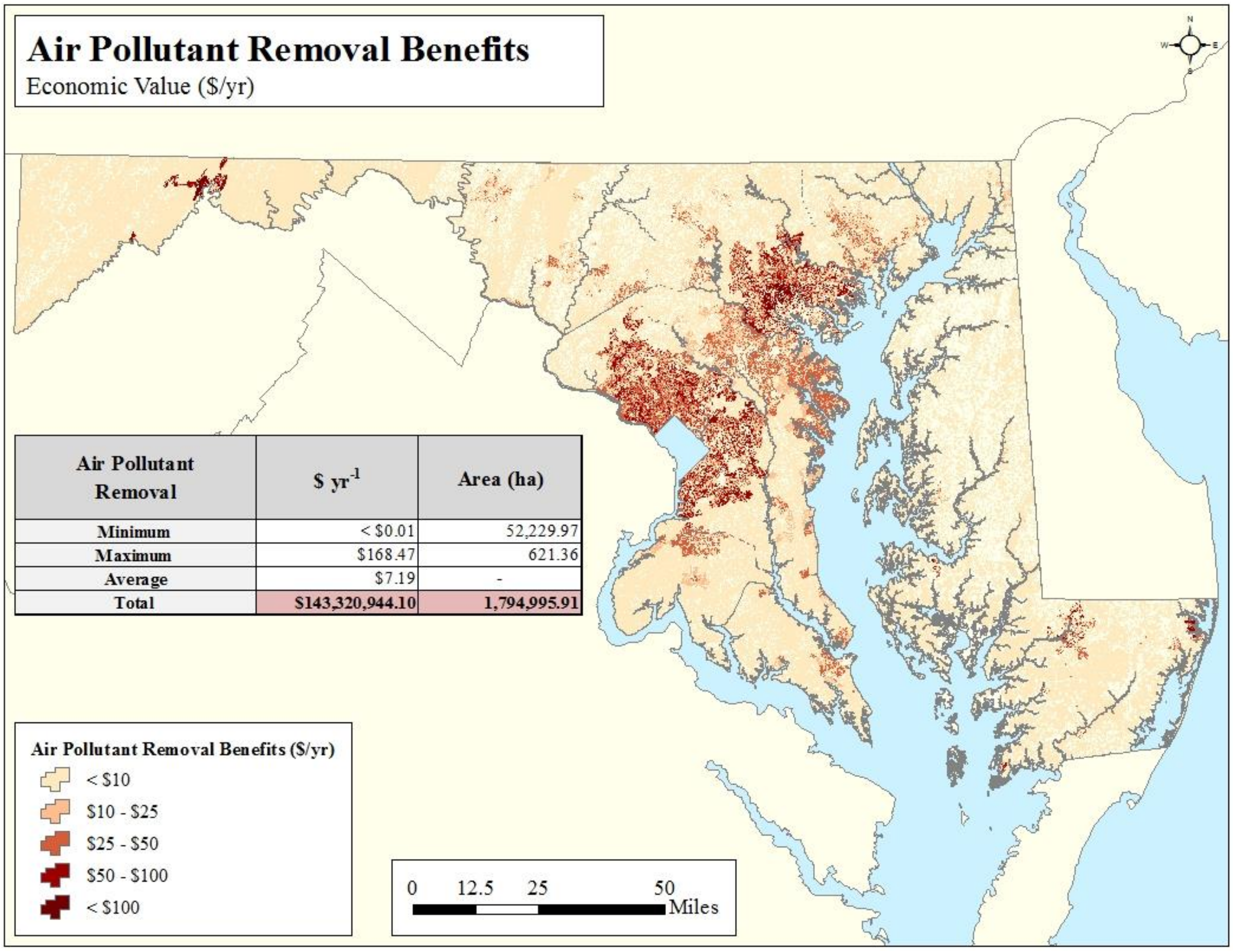
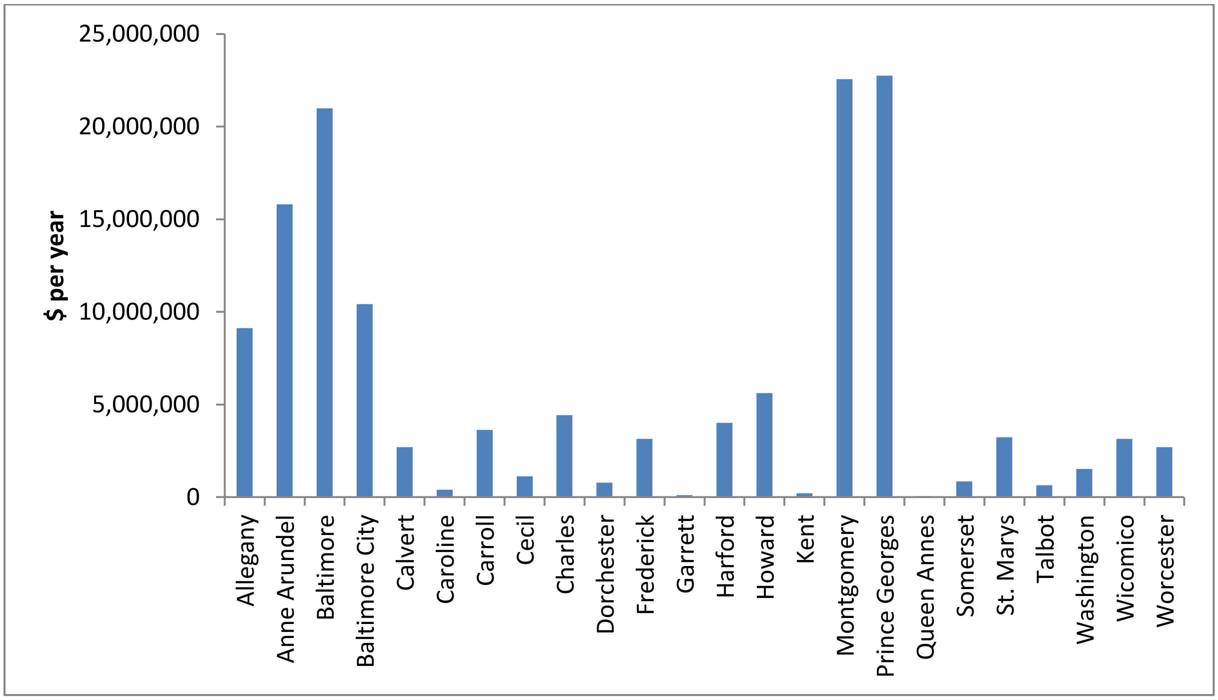


Figure 14. Economic value of air pollutants reduced by tree canopy in Maryland

County Comparison



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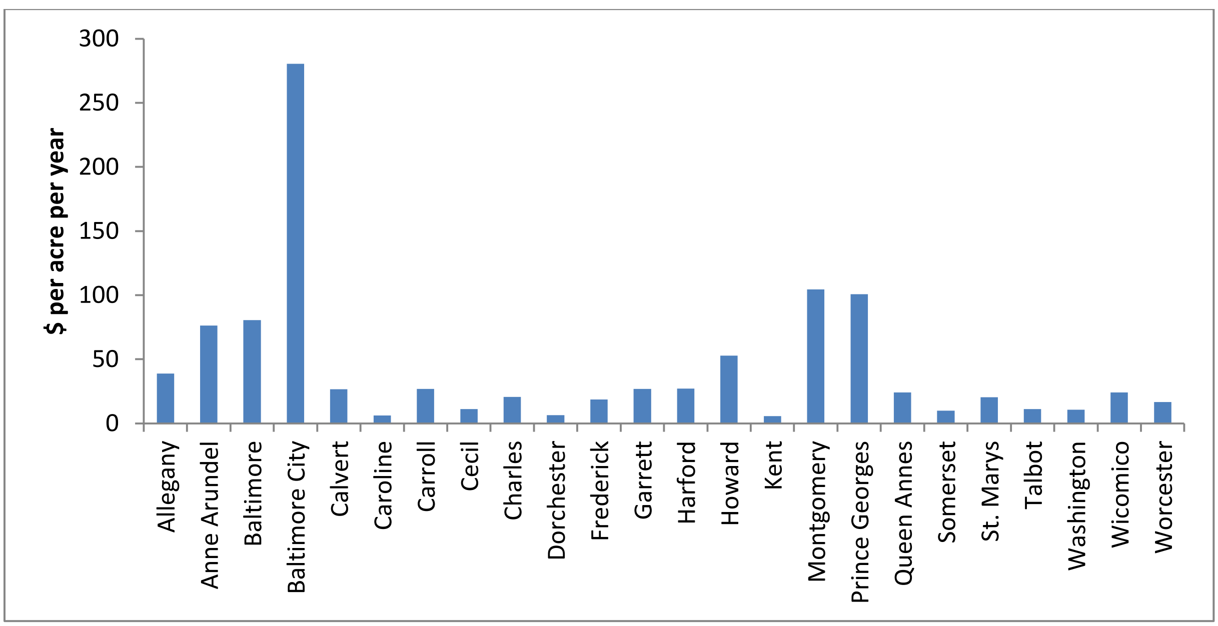

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Figure 15. a) Sum of air pollution ecosystem service by county b) average value per acre by county

Flood Prevention and Stormwater Mitigation

Forest canopies intercepts a portion of precipitation during rainfall events, while ground vegetation and pervious soil in forests and wetlands further slows the surface flow of water, allowing for a portion to infiltrate into the soil. Together, these ecosystems function to decrease the rate and volume of rainfall discharge into waterways, decreasing flood risk during storm events. Increasing urbanization of the state of Maryland is resulting in a state covered by an increasing amount of impervious surface, yielding more runoff when it rains. This creates several problems; higher risk of homes or businesses being flooded, the runoff carries pollutants with it, decreasing water quality, high volumes of water can erode the banks of streams and rivers, and less land is available for water to seep into the ground to recharge drinking water aquifers. Forests help to mitigate all of these problems; comparatively little water runs off forest land in an average storm, much of it seeps into the ground and what does run off does not carry the nutrient and sediment load that urban runoff does. Increasing the amount of forest land in a watershed can help decrease the cost of treating polluted water and protects this precious resource for future generations.

Quantifying Flood Prevention across the Landscape

Several factors determine the amount of stormwater runoff that is stored on the landscape. Riparian areas and forests and wetlands in watersheds with high impervious area upstream receive larger amounts of stormwater runoff. The type of soil, presence of floodplain, whether in a riparian area, type of wetland, and the impervious surface percentage of the surrounding watershed all factor into how much water runs off into the area and the ability of the area to absorb that water. All of these factors were considered when ranking the ability of forests and wetlands in Maryland to reduce stormwater runoff. This rank was related to the stormwater ecosystem service by observing the range of stormwater volumes treated by forests or wetlands.

A modified version of the Watershed Resource Registry Stormwater Preservation model[40] was used to rank the relative capacity and stormwater load across the landscape from 1-5 (figure 16). The model was modified by removing targeting classifications from the model (targeted ecological areas, stronghold watershed, etc.) and adding a factor for slope of the landscape into the ranking algorithm. We used the Maryland Stormwater Design Manual[41] and the Virginia Stormwater Management Handbook[42]

[40] Watershed Resource Registry (2016)
[41] MD Department of the Environment (2009)

to estimate the range of stormwater volumes treated. Table 7 displays the depth of stormwater treated attributed to the ranking for forests and for wetlands.

Table 6. Ranking of forest and wetland potential for mitigation of stormwater runoff and flooding

Stormwater and Flood Mitigation Rank	1	2	3	4	5
Forest, depth treated (m/yr)	0.5	0.75	1	1.25	1.5
Economic Value (per acre)	$517	$776	$1,034	$1,293	$1,551
Wetland (depth treated, m/yr)	0.75	1	1.5	2	2.25
Economic Value (per acre)	$803	$1,071	$1,606	$2,141	$2,409

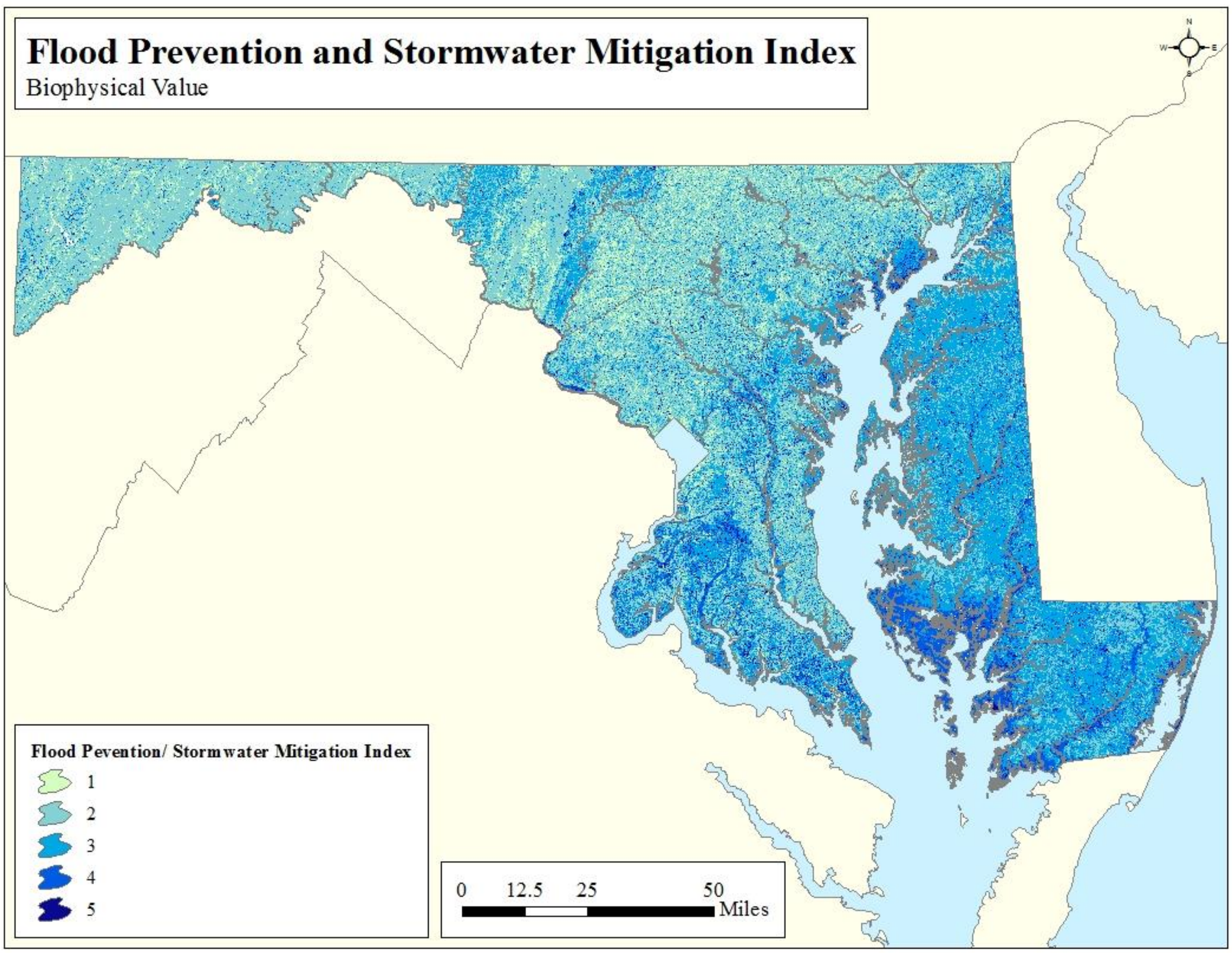


Figure 16. Index of flood prevention/stormwater mitigation across Maryland

[42] VA Department of Environmental Quality (2013)

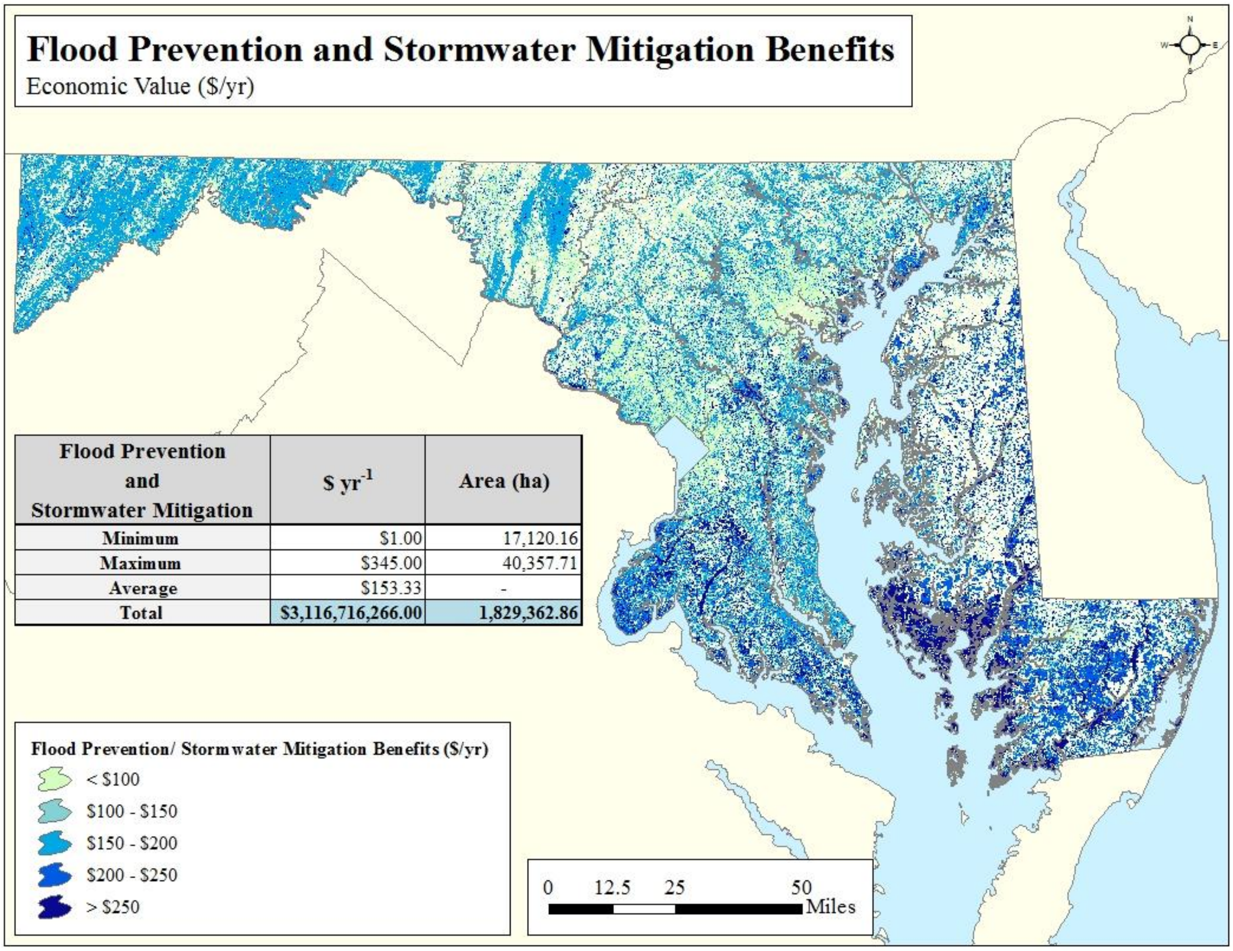
Valuing Flood Prevention and Stormwater Mitigation

Instances of payment used to calculate the average eco-price of flood prevention and stormwater mitigation are summarized in Table 8. We considered the Stormwater Remediation fee[43] and numerous cost estimates for stormwater infrastructure, as prepared by King and Hagan for the State of Maryland in 2011[44], and the benefits forests and wetlands have in reducing flood insurance premiums[45]. This is the largest service we considered, totaling $3.1 billion per year in Maryland (figure 17). Figure 18 shows how this service varies by county in total value and on a per acre basis.

Table 7. Eco-price used to calculate the flood prevention/stormwater mitigation ecosystem service value

Biophysical Category and Measure	Eco-Price	Units	Exchange Classification
Flood insurance benefits	$0.05	$/m^3 runoff avoided	Cost Savings
Average Stormwater Remediation fee	$0.18	$/cubic meter (m^3) runoff	Tax
Erosion and Sediment Control	$0.22	$/m^3 stormwater treated	Replacement cost
Vegetated Open Channels	$0.35	$/m^3 stormwater treated	Replacement cost
Wet Ponds and Wetlands (New)	$0.38	$/m^3 stormwater treated	Replacement cost
Urban Grass Buffers	$0.38	$/m^3 stormwater treated	Replacement cost
Urban Nutrient Management	$0.52	$/m^3 stormwater treated	Replacement cost
Urban Forest Buffers	$0.54	$/m^3 stormwater treated	Replacement cost
Bio-swale (new)	$0.57	$/m^3 stormwater treated	Replacement cost
Dry Detention Ponds (new)	$0.63	$/m^3 stormwater treated	Replacement cost
Dry Extended Detention Ponds (new)	$0.63	$/m^3 stormwater treated	Replacement cost
Wet Ponds and Wetlands (Retrofit)	$0.71	$/m^3 stormwater treated	Replacement cost
Infiltration Practices w/o Sand, Veg. (New)	$0.71	$/m^3 stormwater treated	Replacement cost
Average Replacement Cost	$0.48	$/m^3 stormwater	•
Average of Tax, Cost Savings, and Replacement Cost	$0.33	$/m^3 stormwater	•

[43] MDE (2014)
[44] King and Hagan (2011)
[45] Joyce and Scott (2005)

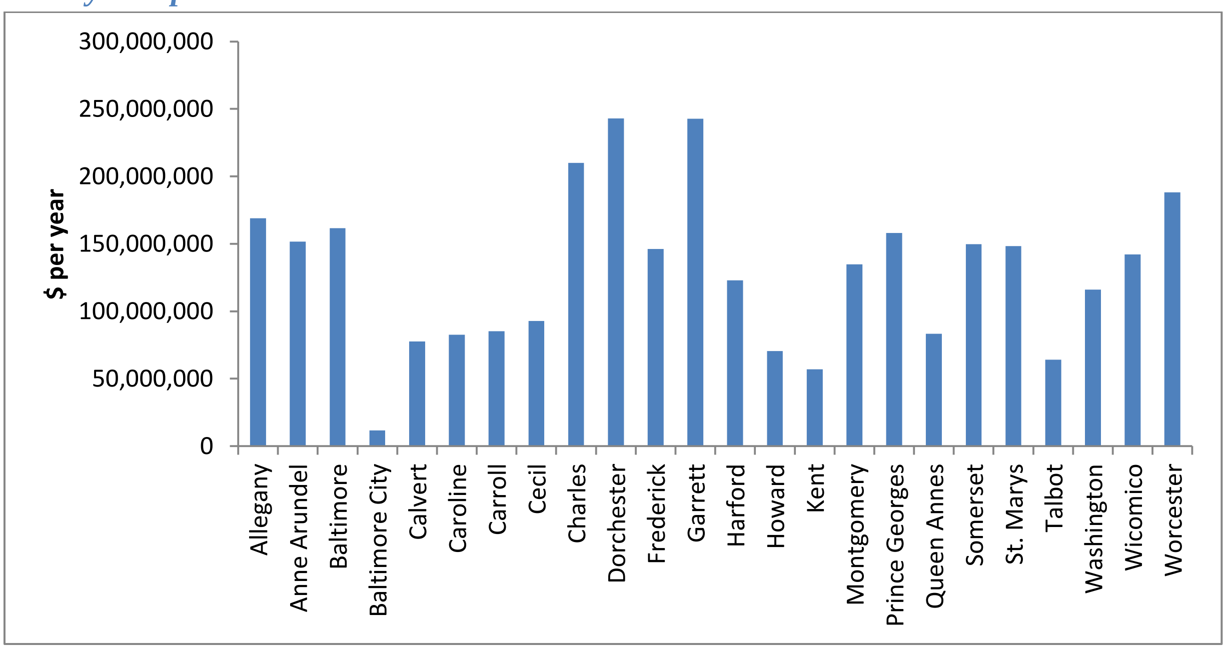


Flood Prevention and Stormwater Mitigation	$ yr^{-1}	Area (ha)
Minimum	$1.00	17,120.16
Maximum	$345.00	40,357.71
Average	$153.33	-
Total	**$3,116,716,266.00**	**1,829,362.86**

Figure 17. Economic value of flood prevention/stormwater mitigation ecosystem service across Maryland

Photo Credit- EA Vaughn Wildlife Management Area

County Comparison



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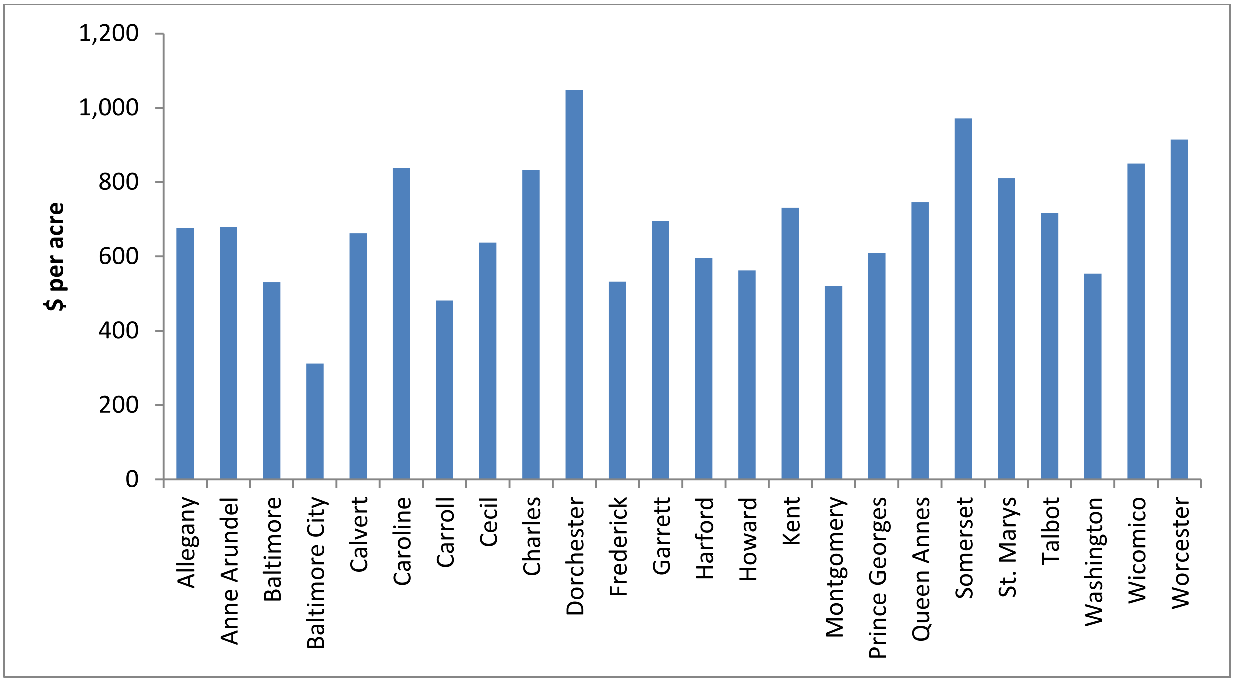


b)

Figure 18. a) Sum of flood prevention/stormwater mitigation ecosystem service by county b) average value per acre by county

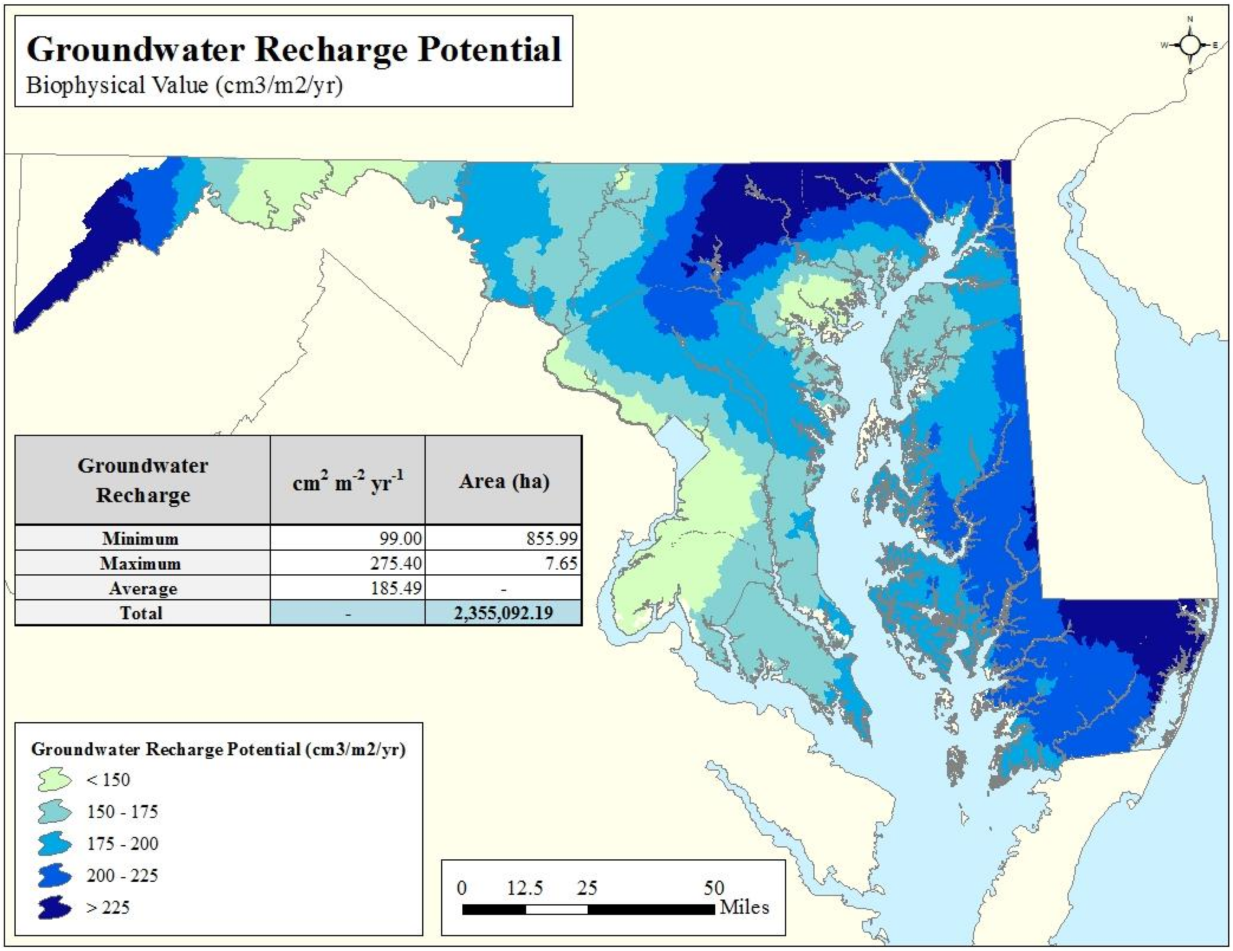
Taylor Island Wildlife Management Area

Groundwater Recharge

Groundwater recharge represents the portion of precipitation that percolates through the soil and enters underground aquifers. Approximately 50% of Maryland residents rely on groundwater as a drinking water source, particularly in Southern Maryland and on the Eastern Shore. While water scarcity is not currently as critical of an issue in Maryland as it is in other parts of the United States, groundwater recharge is a vital component of securing the water supply of the state for the future, particularly in the face of a growing population. Besides drinking water groundwater is important for maintaining flow of rivers and streams important for recreation and wildlife habitat. Parts of southern Maryland rely on the Patapsco and Magothy Aquifers for drinking water supply and both aquifers have been identified by MDE as Water Management Strategy areas due to concerns with excessive drawdown and potential saltwater intrusion.

Quantifying Groundwater Recharge across the Landscape

The underlying geology across the landscape is the primary driver of the rate that water enters unconfined and confined aquifers. The amount of impervious surface and soil condition also affect the amount of water reaching aquifers. The USGS National Hydrography Database (NHD) spatial assessment of groundwater recharge[46] is the data source on which we rely for our assessment.



Groundwater Recharge	$cm^2\ m^{-2}\ yr^{-1}$	Area (ha)
Minimum	99.00	855.99
Maximum	275.40	7.65
Average	185.49	-
Total	-	2,355,092.19

Figure 19. Groundwater recharge across Maryland

Valuing Groundwater Recharge

In assessing the value of groundwater recharge in Maryland we considered the average municipal price of water in Maryland[47], value of water for recreation[48,49], and the cost of investment in watershed

[46] USDA NRCS-USGS (2016)

[47] Washington Suburban Sanitation Commission (2016)

[48] Reardon (2007)

[49] Roland (unpub.)

protection[12] (Table 8). These values average \$0.35 per m^3 water. Instances of payment used to calculate the average eco-price of groundwater recharge are summarized in Table 8.

The spatial distribution of groundwater recharge and associated economic values across Maryland is illustrated in figures 19 and 20, respectively. This service totals \$1.26 billion per year for Maryland. Figure 21 shows the value of the groundwater recharge service by county.

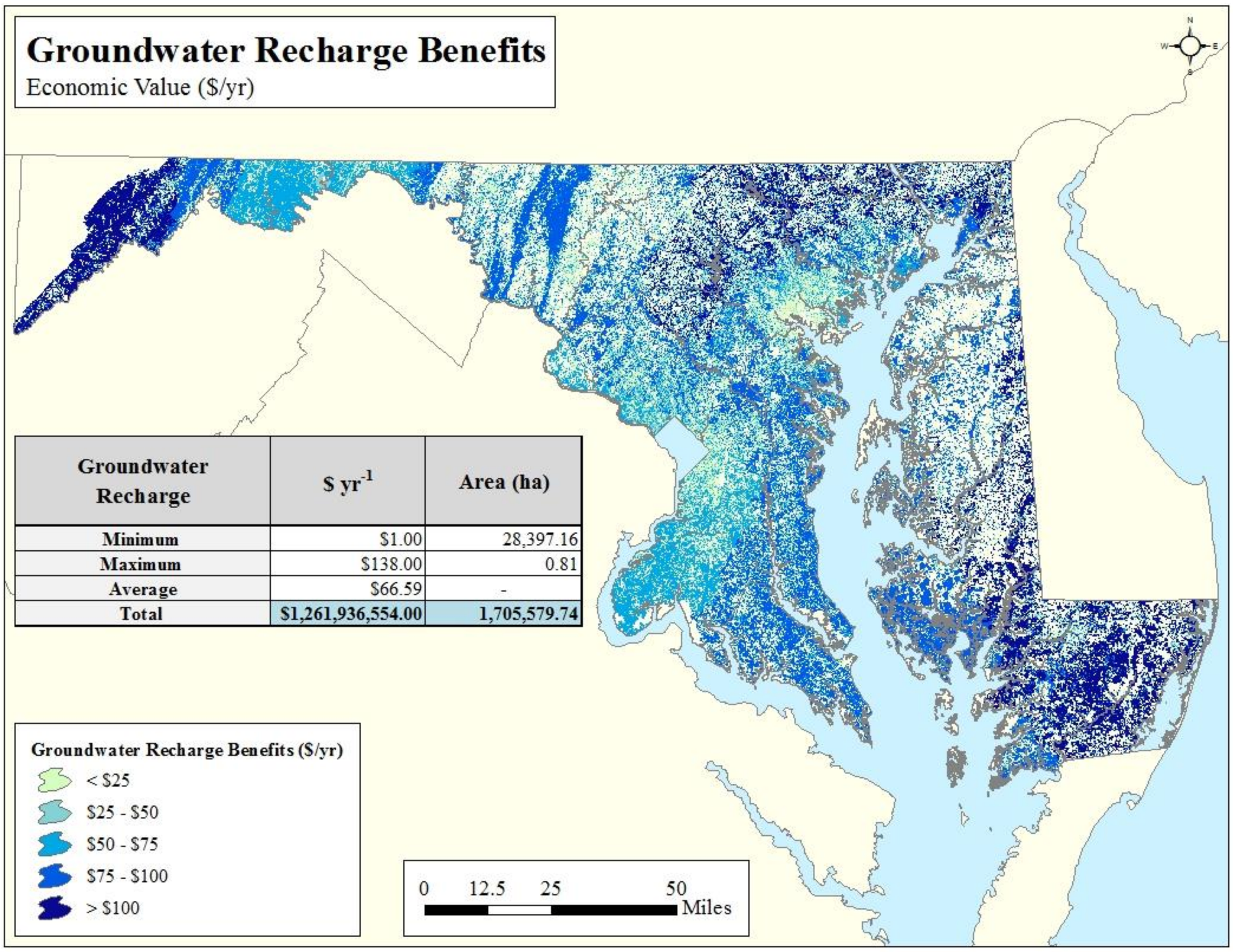
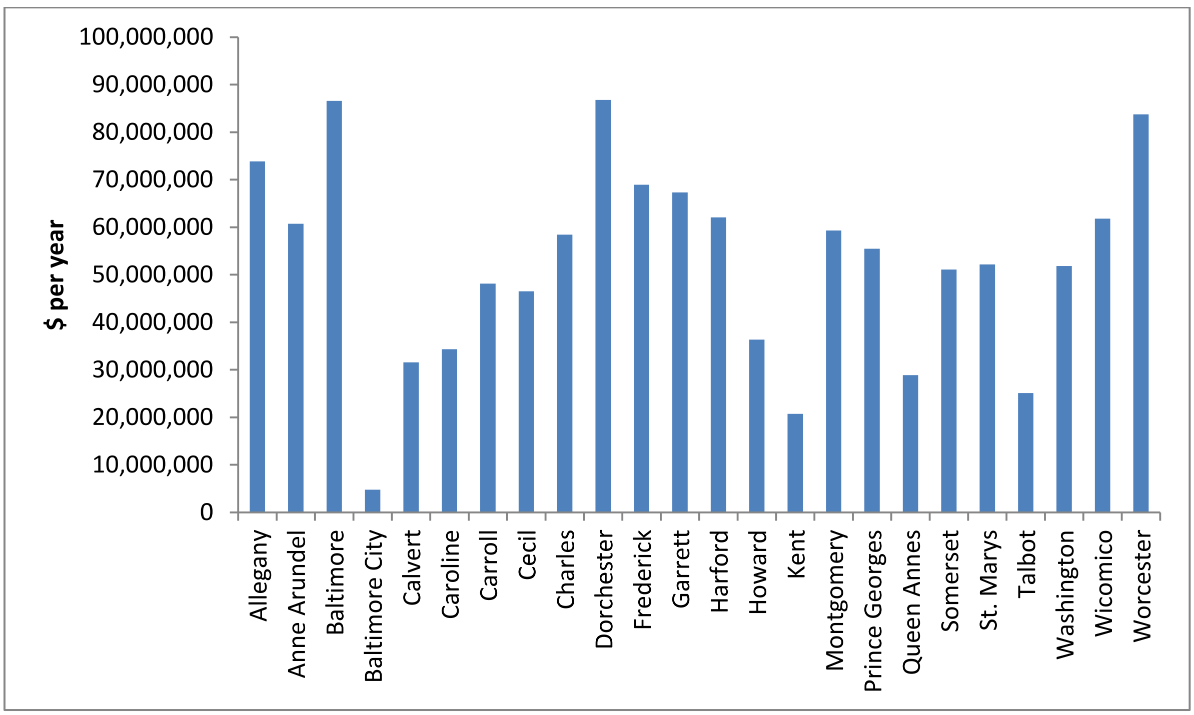


Figure 20. Economic value of groundwater recharge in Maryland

Table 8. Eco-prices used to calculate the groundwater recharge ecosystem service value

Biophysical Category and Measure	Eco-Price	Units	Exchange Classification
Municipal water supply	0.88	$ per m^3	Market Price
Investment in Watershed Protection	0.084	$/$m^3$ of water supply	Investment
Average for recreation	0.073	$ per m^3	Non-market Analysis
Average for Groundwater	$0.35	$ per m^3	•

County Comparison



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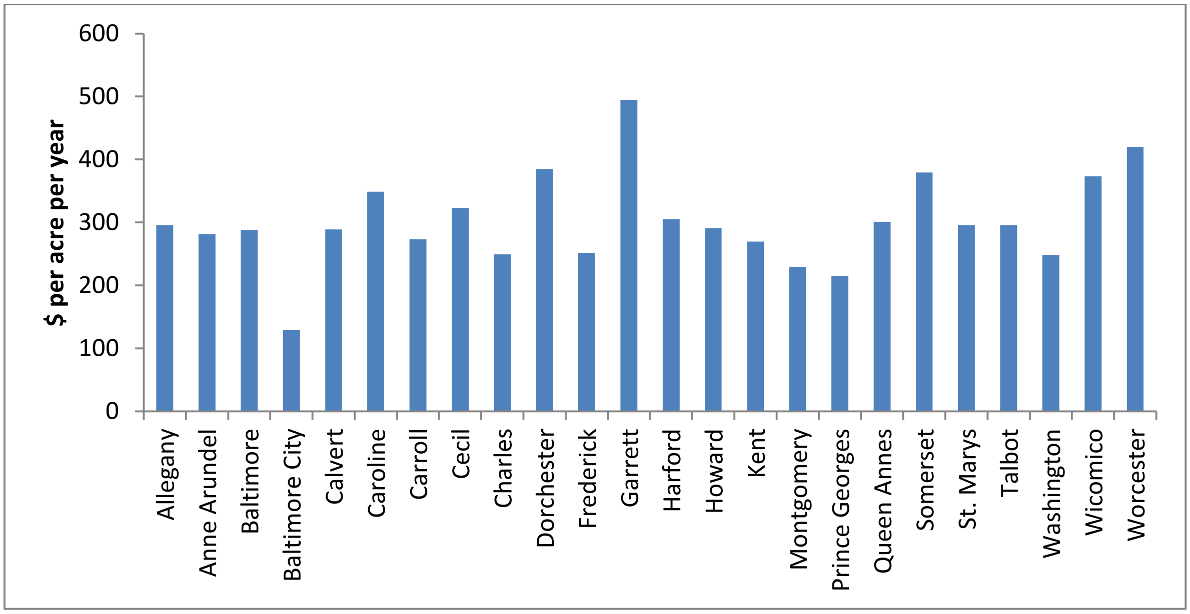


b)

Figure 21. a) Sum of flood prevention/stormwater mitigation ecosystem service by county b) average value per acre by county

Surface Water Protection

About half of the water supply in Maryland is sourced from reservoirs. Natural lands are exceptionally important in maintaining water quality in reservoirs, reducing the cost to treat the water to water supply standards[50,51]. The five major reservoirs in Maryland, Loch Raven, Liberty, Pretty Boy, Tridelphia, and Rocky Gorge are the major water sources for residents of the densely populated Baltimore-Washington corridor. The forests and wetlands within the watersheds of these reservoirs are of unique economic value, as help to provide clean water, reducing the cost of treatment, and avoiding the cost of expensive water treatment plant upgrades to maintain quality standards.

Quantifying Surface Water Protection across the Landscape

While there are other smaller instances of surface water for water supply in Maryland we focused on the watersheds of the five major reservoirs in Maryland for this analysis. The smaller sources were more difficult to quantify the amount of water being supplied and the economic benefit of the forests in the watershed on the water source (figure 22).

Tridelphia Reservoir Photo Credit- Gervase Ryback

[50] Warzniak et al. (2016)
[51] Elias et al. (2013)

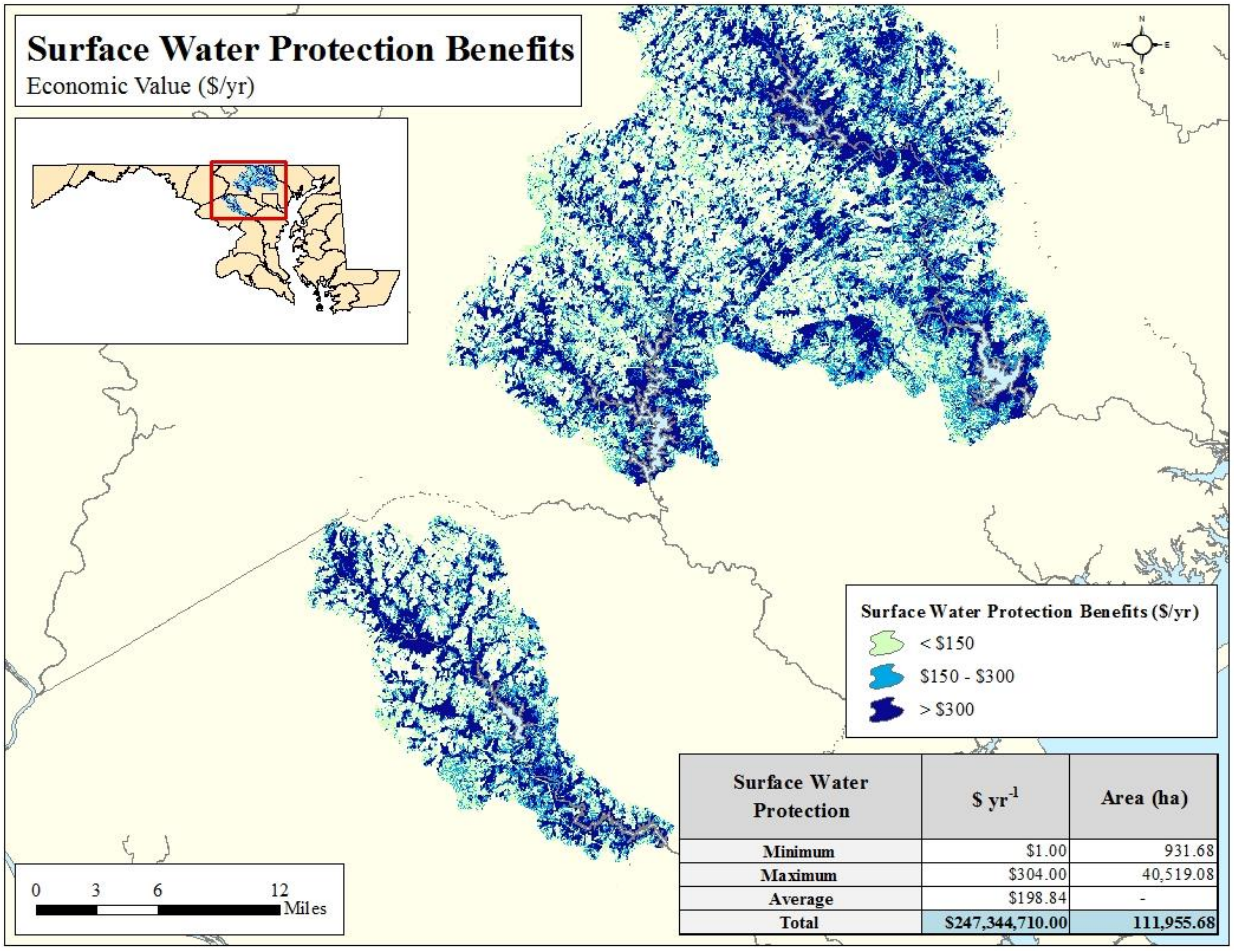


Figure 22. Economic value of surface water protection in Maryland

Valuing Surface Water Protection

We used a different value for the surface water protection eco-price, averaging cost savings of water treatment from having trees in the watershed[50,51], the municipal price of water[47], and the cost avoided of having to upgrade a treatment plant to advanced treatment[52]; these average $1.52 per m^3 of water. Almost all of this service is concentrated in four counties- Baltimore, Carrol, Howard, and Montgomery, totaling $245 of the $246 million of value per year (figure 23).

[52] HDR (2013)

Table 9. Biophysical category and measure

	Eco-Price	Units	Exchange Classification	Reference
Water treatment costs reduced	$0.02	$/m^3	avoided cost	Elias et al. 2013, Warzniak 2016
Provision of municipal water in MD	$0.79	$/m^3 water supplied	market price	WSSC 2014
Costs avoided of upgrading to advanced treatment facility	$3.76	$/m^3	avoided cost	HDR 2013
average	$1.52	$/m^3		

County Comparison

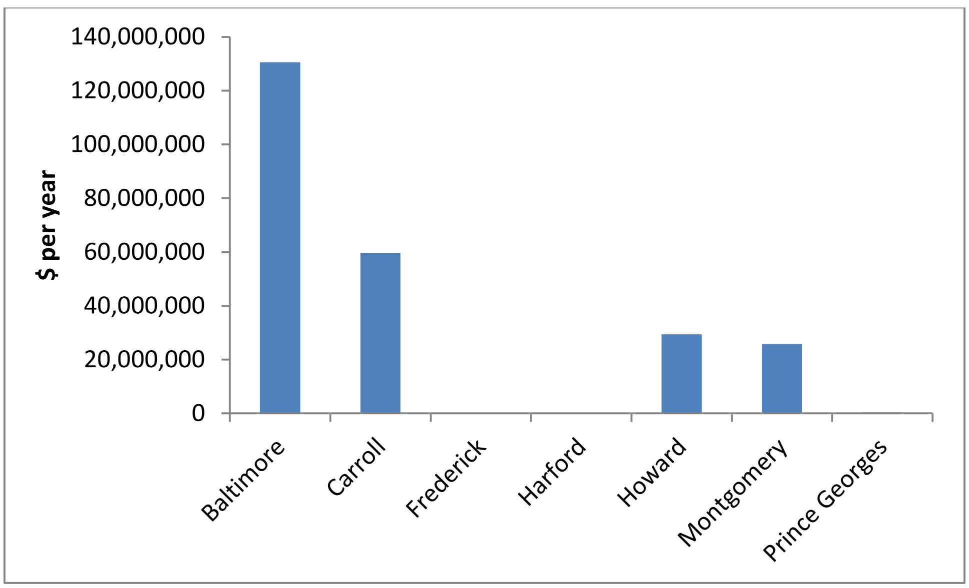


Figure 23. Sum of surface water protection ecosystem service by county

Nitrogen Removal

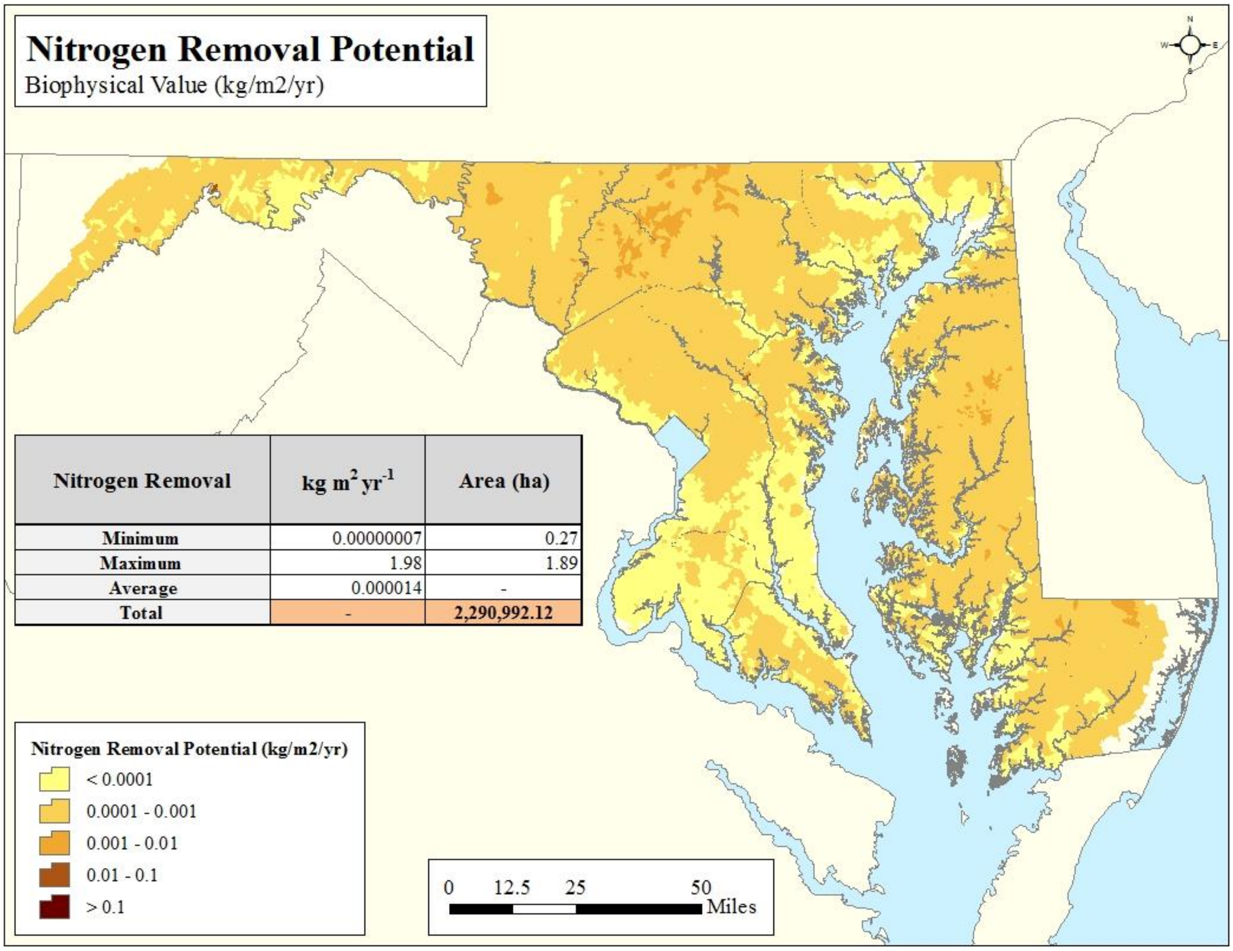
Addressing the impacts of nutrient pollution is critically important to the Chesapeake Bay watershed. The Chesapeake Bay is a classic example of an overexploited resource, with impacts from overfishing being compounded by nutrient pollution. Historically, the forests and wetlands of the Chesapeake Bay watershed absorbed nutrient loads resulting from agriculture, urban land use, and waste products. However, in the past century, the capacity of our natural lands to absorb excess nutrient loads has been exceeded due to population growth coupled with forest and wetland loss. This has led to excess nutrients entering the Chesapeake Bay. Excess nutrients in waterways cause harmful algal blooms, which then decompose and deplete oxygen levels in the water, leading to increased dead zones and poor water quality. This process, known as eutrophication, negatively impacts the health of the Bay and impedes the ability of fisheries to be productive. In order to restore the Bay from its degraded state, we must replace the services that were being performed by ecosystem services by either restoring natural lands or implementing nutrient removal technologies, both costly options.

Quantifying Nitrogen Removal across the Landscape

Forests and wetlands in watersheds with high amounts of urban or agricultural land-uses receive and take-up higher quantities of nutrients. Forests and wetlands have a finite ability to take up nutrient inputs and a number of factors work to determine the quantity of nutrients absorbed, including the type of forest or wetland and the timing of nutrient inputs (more nutrients will be taken up during the growing season). Through literature review it was found that in estuarine wetlands salinity is a significant factor in the ability to process and store nitrogen, with more saline wetlands tending to be more efficient in nitrogen removal. Freshwater wetlands in floodplains process and store higher quantities of nitrogen than isolated wetlands.

The USGS SPARROW (Spatially Referenced Regression on Watershed Attributes)[53] model simulates the loading of nitrogen and phosphorus across the Chesapeake Bay watershed based on land-use, incoming nutrients from other watersheds, and atmospheric deposition. Loading rates are then used to assign low, medium, and high nutrient uptake rates (figure 24) based on a range of uptake rates for forests and wetlands taken from the academic literature. Average nutrient uptake rates for each forest and wetland category are summarized in Table 10.

[53] Ator et al. (2011)



Nitrogen Removal	kg m^2 yr^{-1}	Area (ha)
Minimum	0.00000007	0.27
Maximum	1.98	1.89
Average	0.000014	-
Total	-	**2,290,992.12**

Figure 24. Potential for removing nitrogen across Maryland

Table 10. Nitrogen removal rates for forests and wetlands in Maryland

Ecosystem Type	Nitrogen Removal Rate	Reference
	kg/ha/yr	
Forest		
Low N Loading Watershed	5	CBP 2008[54]
Mid N Loading Watershed	10	CBP 2008
High N Loading Watershed	12	CBP 2008
Floodplains Wetlands		
Low N Loading Watershed	30	CBP 2008
Mid N Loading Watershed	80	CBP 2008
High N Loading Watershed	150	CBP 2008
Depressional Wetlands		
Low N Loading Watershed	10	CBP 2008
Mid N Loading Watershed	25	CBP 2008
High N Loading Watershed	50	CBP 2008
Estuarine Wetlands		
Tidal Fresh (0-2.5 ppt)	1750	Merrill & Cornwell 2000[55]
Brackish (2.5-18 ppt)	300	Merrill & Cornwell 2000, Kemp 2006[56]
Salt (18+ ppt)	900	Thomas & Christian 2001[57]

[54] Chesapeake Bay Program (2008)

[55] Merrill & Cornwell (2000)

[56] Kemp (2006)

[57] Thomas & Christian (2001)

Valuing Nitrogen Removal

We value nitrogen removal by observing the average cost to remove nutrients using best management practices[58], what the state provides for the BMP cost share program[59] and through the Bay Restoration Fund[60], and the price on nutrient trading markets[61]. This averages $8.36 per lb nitrogen or phosphorus. Instances of payment used to calculate the average eco-price of nutrient uptake are summarized in table 11.

The spatial distribution of stormwater mitigation and associated economic values across Maryland is illustrated in figure 25. Urban and agricultural lands are particularly important nutrient sources, and forests and wetlands in watersheds with high incidence of these land-uses tend to have high values of the nutrient removal service (see Figure 25). This service totals $402.6 million per year for Maryland. Dorchester and Somerset counties have the highest totals and per acre values for this service due to the abundance of high salinity wetlands in these counties (see figure 26 for totals and per acre values in each county).

Table 11. Eco-prices used to calculate the nitrogen removal ecosystem service value

Biophysical Category and Measure	Eco-Price	Units	Exchange Classification
MD BMP Cost-Share Program	$3.67	$/kg N	Cost of regulation
BMP, Conservation planning	$4.64	Costs/kg N	Avoidance cost
BMP, Grass buffers	$5.26	Costs/kg N	Avoidance cost
BMP, Forest buffers	$6.95	Costs/kg N	Avoidance cost
Nutrient Trading in Chesapeake Bay Watershed	$8.38	$/kg N	Market price
BMP, Conservation tillage	$15.49	Costs/kg N	Avoidance cost
BMP, Cover crops	$15.53	Costs/kg N	Avoidance cost
BMP, Wetland restoration	$24.20	Costs/kg N	Avoidance cost
Bay Restoration Fund	$29.33	$/kg N	Cost of regulation

[58] Talberth et al. (2015)
[59] MD Department of Agriculture (2014)
[60] MDE (2015)
[61] PA Department of Environmental Protection (2014)

BMP, Enhanced nutrient management	$37.93	Costs/kg N	Avoidance cost
BMP, Barnyard runoff control	$38.46	Costs/kg N	Avoidance cost
BMP, Pasture fencing	$59.16	Costs/kg N	Avoidance cost
BMP, Nutrient management	$60.70	Costs/kg N	Avoidance cost
BMP, Prescribed grazing	$83.34	Costs/kg N	Avoidance cost
Average for Nutrient Management BMPS	$31.97	Costs/kg N	Avoidance cost
Average for Nutrients	**$18.34**	$/kg N	

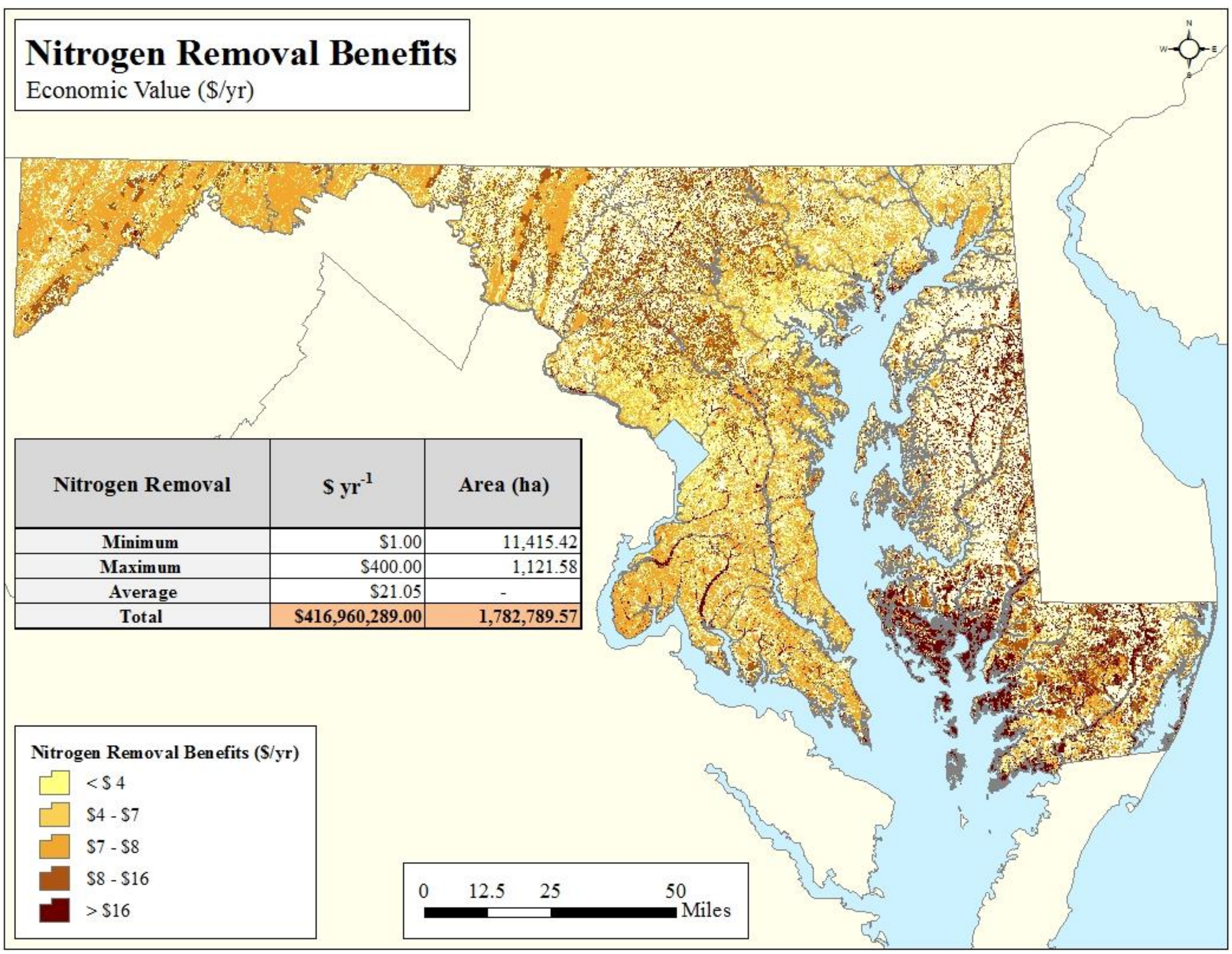
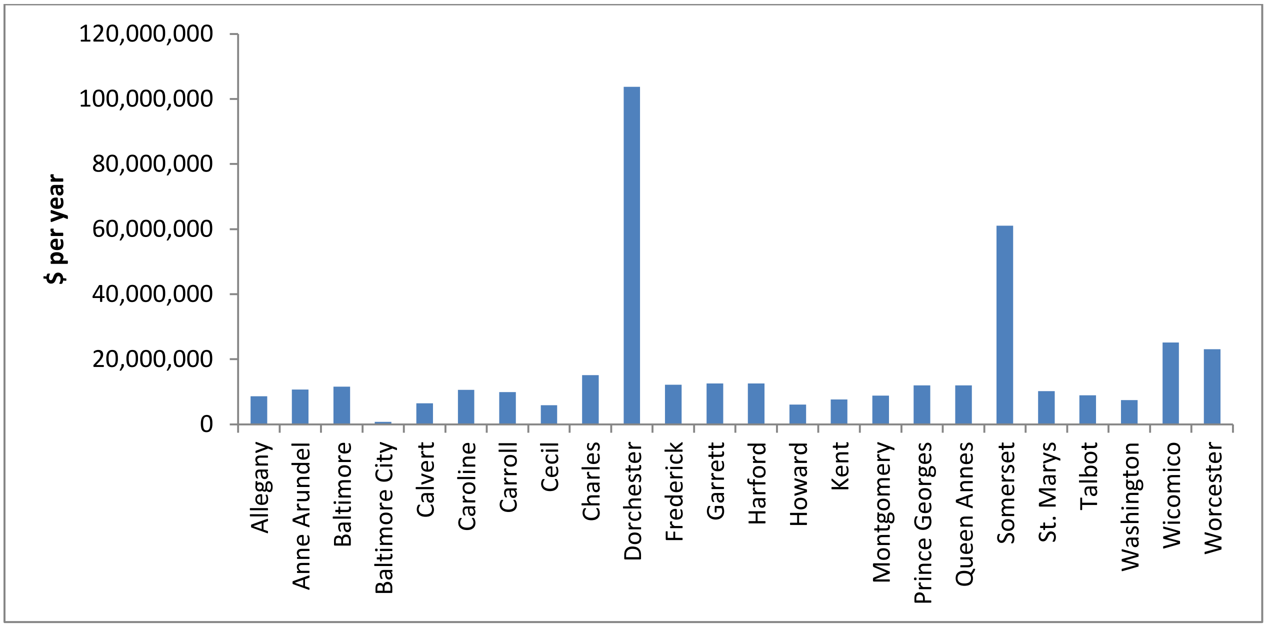
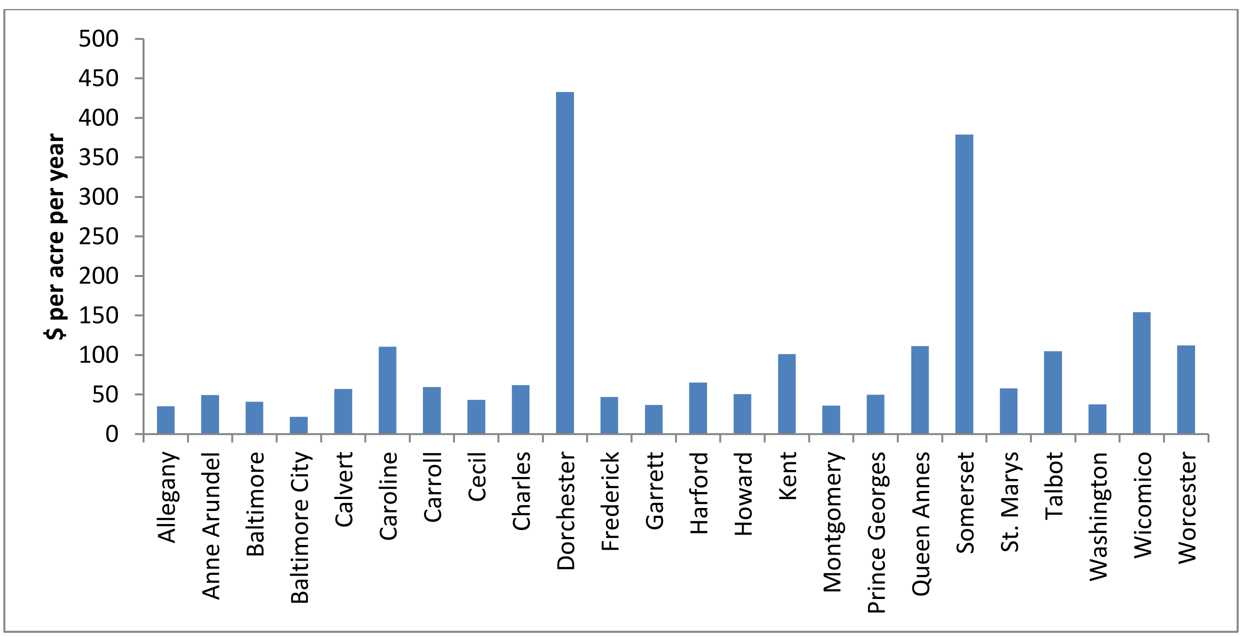


Figure 25. Economic value of nitrogen removal ecosystem service across Maryland

County Comparison



a)



b)

Figure 26. a) Sum of nitrogen removal ecosystem service by county b) average value per acre by county

Recreation

Outdoor recreation is very valuable to Maryland's economy and while our work does not include assessing this value, there are other sources for this information. The US Fish and Wildlife Service last conducted a survey study in 2011 which found that people spent nearly $1.3 billion dollars a year on wildlife viewing, hunting, and fishing in Maryland[62]. The Outdoor Industry Association conducts annual estimates of the economic impact of outdoor recreation on the US economy and for each state. They found that the Maryland outdoor industry generated $14 billion of consumer spending, 109,000 jobs, $4.4 billion in wages and salaries, and $951 million in state and local taxes in 2016[63]. A 2010 study specifically for Maryland Parks found that they have an economic impact of $650 million per year and support over 10,000 jobs in Maryland[64]. Figure 27 shows opportunities for outdoor recreation in Maryland, including public lands, water access points, and trails. The Maryland DNR has several online tools to help users find recreational opportunities, including the Maryland Trail Atlas, Water Access Guide, Fishing Access, and Recreation Atlas. Many of these resources can be accessed through mobile devices on the Access DNR app.

Photo Credit- James Corbett DNR Photo Contest 2015

[62] U.S. Department of the Interior (2011)
[63] Outdoor Industry Association (2017)
[64] Doughtry (2011)

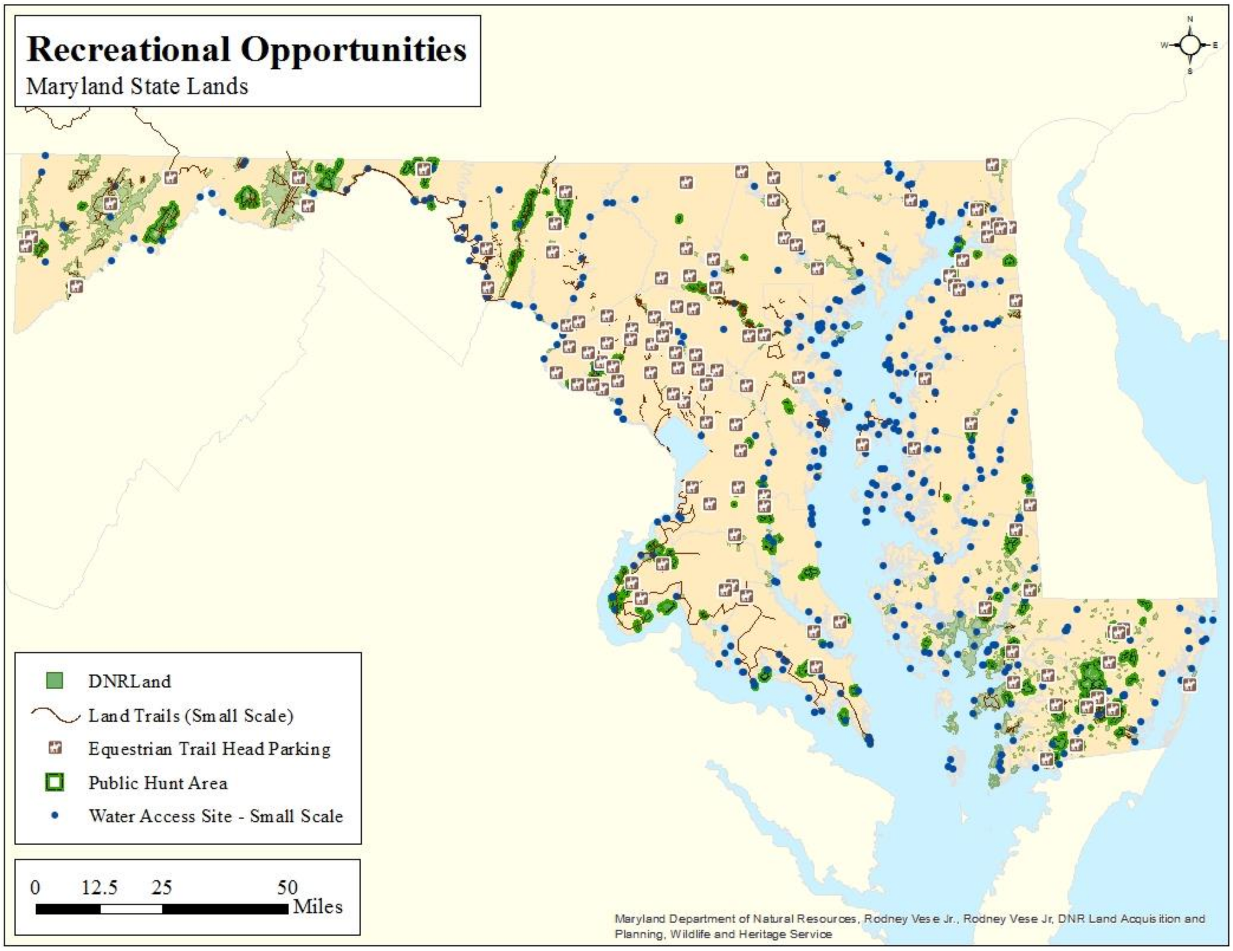


Figure 27. Recreational opportunities in Maryland (from Maryland Trail Atlas)

ECOSYSTEM SERVICE SUMMARY

When totaling the seven ecosystem services from natural lands in Maryland considered in this assessment (air quality, carbon sequestration, nitrogen removal, surface water protection, groundwater recharge, wildlife habitat, and flood prevention/stormwater mitigation) we estimate that these services provide $8.0 billion of benefits every year to the people of Maryland (figure 28). Counties with large areas of forests and wetlands tended to have higher total and per acre values (figure 29). The two largest services (flood prevention/ stormwater mitigation and wildlife habitat) form the majority (71%) of this total. The work presented here does not include all of the benefits people receive from Maryland's ecosystems; we do not include benefits already accounted for in economic markets such as outdoor recreation, hunting and fishing, and timber extraction and will be adding ecosystem services specific to the Chesapeake Bay in future work.

Ecosystem Services across the Landscape

Each ecosystem service varies across the landscape. Certain services, like air pollution, stormwater mitigation and flood control, are a function of both the supply (e.g., amount of air pollutants removed) and demand (e.g. population vulnerable to the air pollution). On a per acre basis these services were found to generally be higher in suburban settings or areas of high vulnerability. Other services were only supply based, and tended to be higher in rural areas, like wildlife habitat provision. When viewed in total counties with larger areas of forests and wetlands had higher ecosystem service values, as one would expect. Counties with greater wetland areas, particularly Eastern Shore counties with large areas of coastal wetlands like Dorchester and Wicomico, tended to have the highest per acre values. On average, coastal emergent wetlands in Maryland average $2,623 per acre, forested terrestrial wetlands averaged $2,292 per acre and forests averaged $1,546 per acre of benefits supplied every year. In total, these yearly benefits are $572 million for coastal emergent wetlands, $1.59 billion for forested wetlands, and $5.9 billion for terrestrial forests in Maryland. The maximum per acre ecosystem service value observed was $5,816 per acre per year, however this confluence of high value ecosystem services was rare, the common maximum value observed was ~$4,500 $ per acre per year.

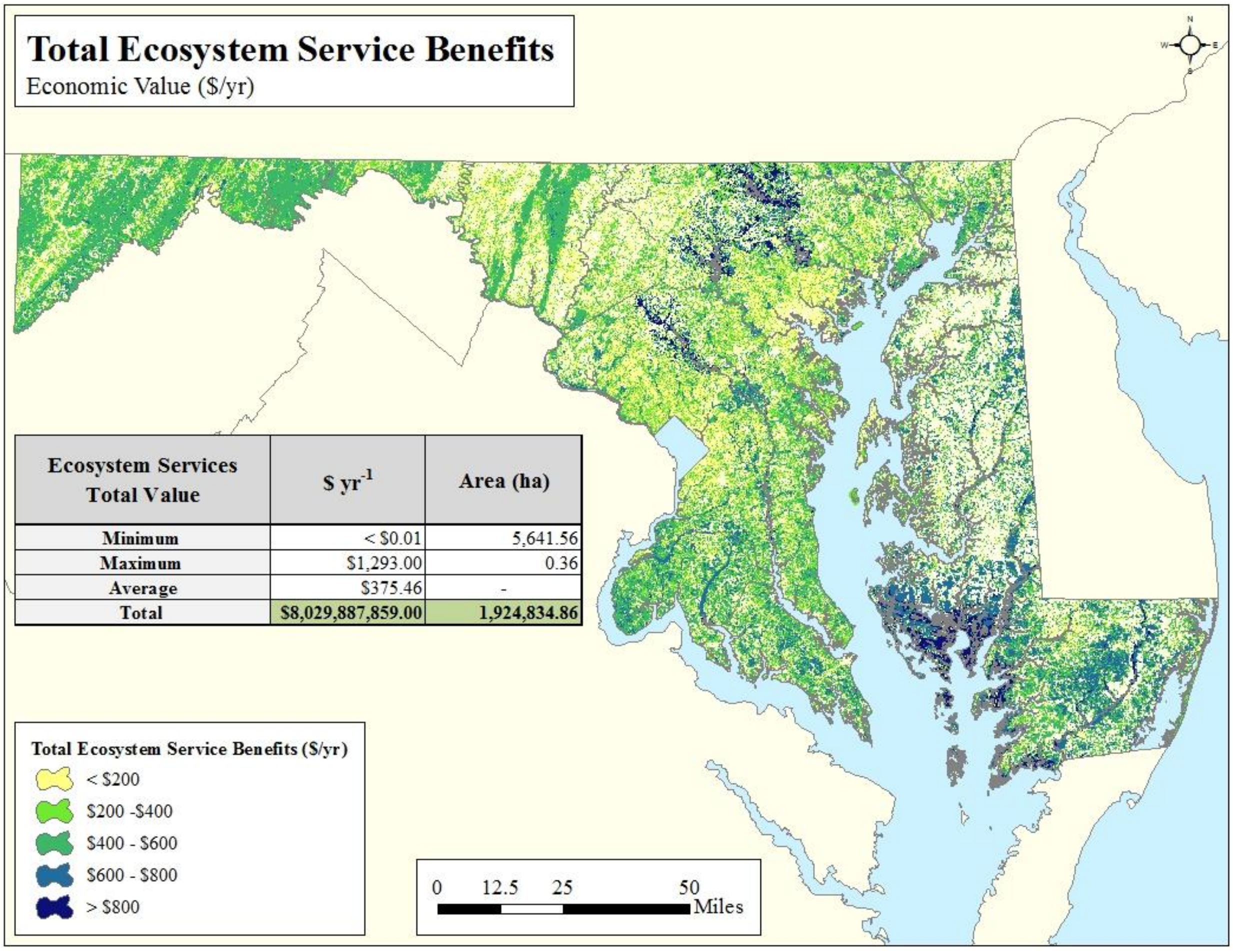
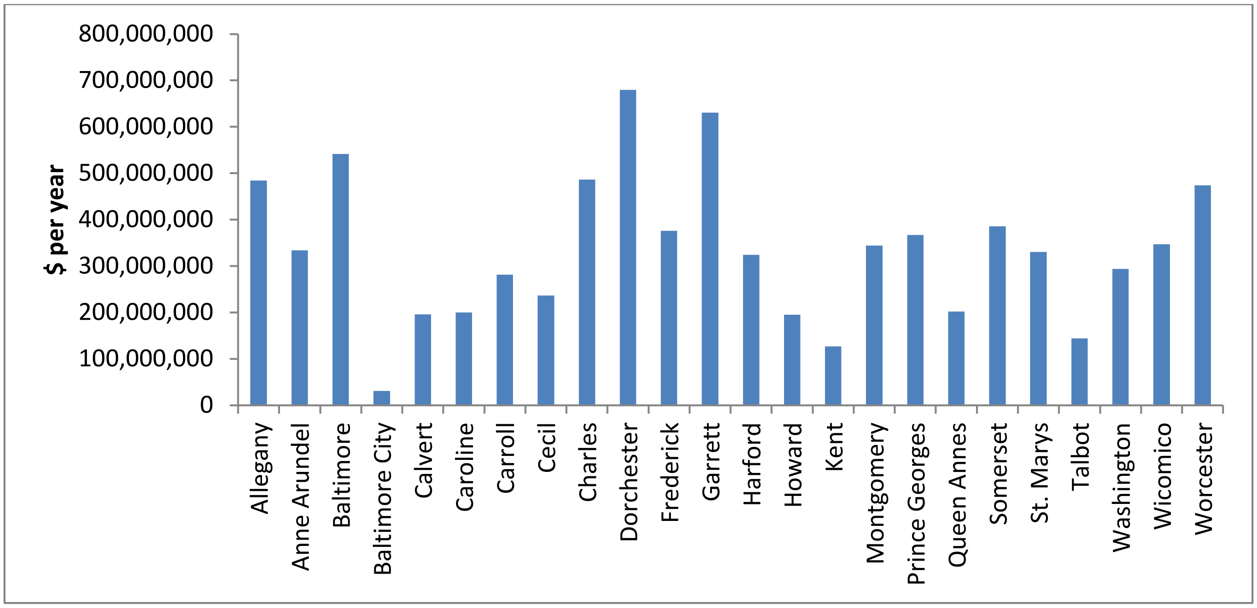


Figure 28. Sum of the economic value of all seven non-market ecosystem services across Maryland

County Comparison



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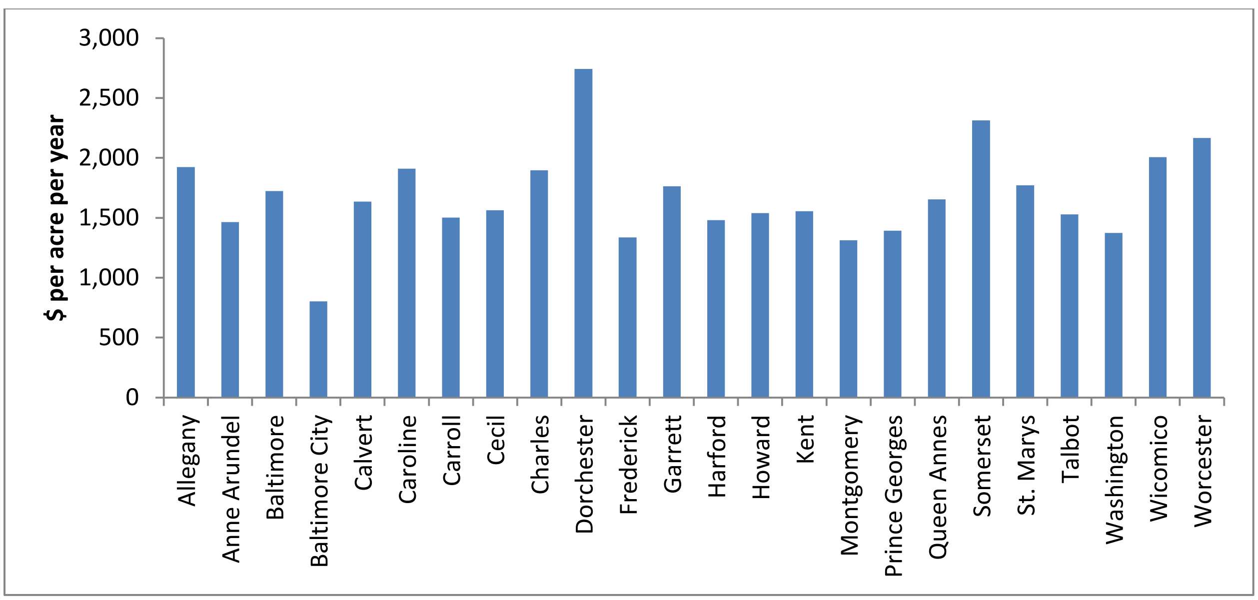

b)

Figure 29. a) Sum of all non-market ecosystem services by county b) average value per acre by county

Discussion

IMPLICATIONS OF THE ECOSYSTEM SERVICE ASSESSEMENT

There are many implications and potential applications of the ecosystem services assessment of Maryland. Ecosystem service values can be considered when deciding how municipalities or counties meet stormwater or nutrient reduction goals. Ecosystem service values could be used to compare the total benefit of stormwater reduction options between green and grey infrastructure. The return on investment (ROI) is a commonly used economic metric to evaluate the net benefit of making an investment. Ecosystem services can be factored into the benefits of an investment decision in an activity that positively impacts the environment, like conserving natural land, restoring degraded lands to a more natural state, or instituting a regulation designed to improve or protect natural lands. The following are examples where the results of this study could be influential to these decisions—

In Action: Conservation Return on Investment

Areas of the state having the highest per acre values of ecosystem services could be prioritized for conservation, minimizing the potential loss of services when lands are developed or otherwise impacted by anthropogenic activity. State, federal and county government along with land trusts could prioritize land acquisition in these regions and incentivize transfer of development rights (TDR) away from watersheds of particularly high value. Ecosystem service information is available by land parcel to be considered along with other factors when the state is prioritizing Program Open Space investments through the Parcel Evaluation Tool and several outreach events have been conducted with the Maryland land trust community.

In Action: Evaluation of Ecological Impacts

These results can be used to evaluate the ecosystem service value that is lost when natural lands are developed in the state. Once the quantity of ecosystem service loss is quantified, it could be required that a commensurate value be replaced through restoration or paid for in fees. This will require mitigation ratios or fee rates greater than what is currently required, as the loss of mature forests or wetlands is typically replaced with newly planted forests or restored wetlands which lack the full functioning capacity of mature ecosystems, and their associated ecosystem services. This approach is currently being put into policy by the Maryland DNR, with a pilot evaluation already completed of a natural gas line impact at Fair Hill State Park. The compensatory value was accepted and paid by the Eastern Shore Natural Gas company. This approach does have limitations in that a monetary investment will still have a time lag between spending on restoration or management activities, still possibly not fully compensating for value lost, and should be combined with a holistic, long term, approach at the watershed scale for projecting impacts of development on ecosystem function, combined with planning efforts to avoid these impacts.

Planned: Restoration Return on Investment

Comparison of the cost of implementing certain programs to the uplift in ecosystem services through expanding or restoring natural lands (e.g. reforestation, wetland restoration) is a potential application of this analysis. The addition of ecosystem service value allows additional benefits of restoring natural lands to be realized, incentivizing restoration of degraded systems. Restoration activities are most appropriate in more impacted regions where ecosystem services like stormwater mitigation and nutrient removal will be higher. We plan on including ecosystem service when evaluating restoration opportunities through the DNR and our funding programs.

Planned: Regulatory Return on Investment

Results indicate that regulations like Critical Area protection and low density zoning that reduce allowable impervious cover and the intensity of development likely provide a high return in terms of ecosystem service value for a relatively low investment. Examples include Resource Protection Zones (RPZ) or conservation districts in the State. Protected lands were shown to be very effective in identifying high value areas and managing them in a manner that maximizes the value of services, implying that current protected lands should be maintained and that additional investment in protecting natural lands is justified. State owned lands have an average value of $2500 of ecosystem services per acre, compared to $1717 per acre for all natural lands in the state. At the local level, Zoning and Subdivision regulations are the regulatory documents governing development. Recognizing the value ecosystem services have in the land use planning process will likely lead to additional investment in preservation and restoration.

An additional potential application of these results is evaluation of what economic value is being lost when natural lands are developed in the state. Once the quantity of ecosystem service loss is quantified, it could be required that a commensurate value be replaced through restoration, thus ensuring a no net loss of ecosystem services in the county. Initial work indicates that this would require mitigation ratios greater than what is currently required, as the loss of mature forests or wetlands is often replaced with newly planted forests or restored wetlands which lack the full functioning of mature ecosystems, and the associated ecosystem services. A direct no-net loss approach does have limitations, and should be combined with a holistic, long term, approach at the watershed scale for projecting impacts of development on ecosystem function, combined with planning efforts to avoid these impacts. A difficulty with the application of a "no net loss" requirement is the ability to assess at what point an ecosystem is impacted enough by development to substantially degrade the function of that system. Ecosystems may be resilient enough to withstand a certain degree of impact or loss to the system without overall irreversible degradation to the overall function of the system. However, at some point impacts can drastically degrade the entire system. The degree and extent of such impact is open for policy debate and further research.

Photo Credit Michael Evermeir DNR Photo Contest 2014

Comparison to Previous Ecosystem Service Valuations in the Chesapeake Bay Watershed

Several studies have valued ecosystem services in the Chesapeake Bay watershed. Kauffman et al.[65] drew from a broad selection of economic and ecosystem service studies to assess the socioeconomic value of the Delaware portion of the Chesapeake Bay watershed. In assessing ecosystem services, the authors rely upon existing studies which use the benefit transfer method to estimate ES values in their

[65] Kauffman (2011)

studied systems. Based on the studies reviewed in Kauffman et al., they estimate the ecosystem service value from forests in the Chesapeake Bay watershed portion of Delaware to be $13,887/acre/y and freshwater wetlands to be $13,351/acre/y, or $1.4 and $1.1 billion per year total benefit to the region, respectively. Phillips and Mcgee[66] analyze the economic benefits of implementing the Chesapeake Bay Clean Water Plan (or Blueprint), showing the natural benefits currently provided and the anticipated increase due to the Blueprint. Their baseline value of natural benefits in the Chesapeake Bay watershed was estimated to be $107 billion per year, and the implementation of the Blueprint was estimated to increase the annual benefits to the region by $22 billion per year. The per acre values for forests and wetlands used in the study were $2835 per acre per year and $1447 per acre per year, respectively. USEPA (2012) examined the impact of considering certain ecosystem services in the algorithm for optimizing Chesapeake Bay restoration strategies to meet federally mandated Total Maximum Daily Load (TMDL) requirements in the watershed. The authors found that when the value of ecosystem services was considered, when optimizing net costs, the total cost of meeting the restoration goals increased by $83 million (from the baseline of $218 million), but an additional $148 million of ecosystem service benefits were added due to the restoration of more natural land area.

The studies summarized here rely upon existing research and the benefit transfer method to determine the value of ecosystem services in the Chesapeake Bay watershed[67,68,69,70,71,72]. Philips and McGee are more inclusive in the ecosystem types and services they consider compared to the work we present; the largest service in their study was aesthetics from open water, measured by increases in home prices associated with water quality, while the USEPA work is more restrictive in both the services and the range of values considered. Kauffman et al. consider a similar range of values as this study, but add valuation methods for ecosystem services instead of averaging them, yielding higher per area values. None of these studies are directly comparable to our results, but are illustrative of the range of valuation methods in practice and the fact that the results we present fall within this range.

[66] Philips and McGee (2014)
[67] Krieger (2001)
[68] Johnston et al. (2002)
[69] Breunig (2003)
[70] NJ DEP (2007)
[71] Weber (2007)
[72] Ingraham (2008)

Double Counting

The potential for double counting is mitigated in this analysis by considering the multiple ways that society pays for different ecosystem services all together, rather than separately. It could be argued that considering the sale value of the land for conservation and the value of land for provision of other ecosystem services would be double counting; however, when the land is sold or put into easement for conservation purposes the intent is most often to preserve the land for wildlife habitat rather than other services. This is particularly true in the case of organizations existing exclusively for this purpose, such as Ducks Unlimited. Even if the payment is partially intended for preserving services, like clean air and water, the eco-prices we consider for non-wildlife services are different ways to pay for the service, independent of their conservation value. In a practical sense, revenue could potentially be generated from carbon sequestration on a land that is conserved, independent of what was paid to conserve the land for wildlife habitat.

Uncertainty

We are measuring two aspects of ecosystem services, the biophysical value and the eco-price, to arrive upon a dollar value, both aspects of which have a degree of uncertainty that is compounded when considered together[73]. For many of the ecosystem service categories there is a large range of values, reflective of the many different ways people pay for the work of the environment. While this could be seen as a weakness of the method, it also demonstrates that variability in social preference is being captured and considered when arriving upon average expected values for the services. We do not present the full range of potential end values, because we are attempting to gain a holistic view of ecosystem service value, and the detailed values in the distribution do not represent how society as a whole values the work of the environment. Again, scale is of utmost importance in assessing ecosystem services. The method we present is best suited to a large scale where payment mechanisms are uncertain. At this scale the alternative is almost always benefit transfer where only one value along the scale of values presented is chosen. Consequently, the arrived upon value will likely either over or underestimate the representative value for the ecosystem service. On a smaller scale, where a specific payment mechanism or policy decision is being sought, another method to assess either social or individual preference may be more suitable, particularly if time and funds are available for a specific study.

[73] Ingwersen (2010)

The Ecosystem Service Paradox

A paradox is a self-contradicting condition. In the case of some ecosystem services, the economic value can be considered a paradox because it reflects the positive economic aspect of the natural system, but the economic value of the service may increase as natural lands are lost. For instance, the stormwater ecosystem service is greater in watersheds with a higher impervious surface percentage and the air quality service is highest in the more densely populated counties. While this is logical from an economic perspective, it does mean that it is not advisable to use maximum ecosystem service provision in the state as a desirable endpoint for policy or as the goal function of a model. These results are most useful in evaluating current condition tradeoffs and decision making.

Conclusions

It is becoming increasingly clear that it is necessary to consider the economic value of ecosystem services in our decision making in order to ensure a sustainable and resilient future. Ecosystem service valuation reveals the economic contributions of natural lands, which can be thought of as the "return on environment" that natural lands provide for residents of Maryland. Society views environmental protection and the continued provision of ecosystem serves as a social, rather than individual, responsibility. Accordingly, social preference is a more appropriate economic perspective to value ecosystem services compared with individual preferences, particularly when informing decision making by a representative government. The value of ecosystem services generated here recognizes the non-market contributions made by natural lands, not typically considered in decision-making by public and private entities and incorporates these values into the decision-making processes, which is likely to increase the long-term sustainability of the social, economic, and ecological system of Maryland, and the well-being of her citizenry. The spatial study analyzes how ecosystem services change over the State both in biophysical supply and economic demand, with applications for how we conserve, restore, and regulate natural lands.

- When considering the value provided on a per capita basis, every citizen of Maryland benefits by $1,333 of ecosystem service value every year, or $111 per month. For context, that roughly equals the average electric in the State in 2015[74].

[74] US EIA (2016)

- Maryland has abundant natural resources and associated ecosystem services, but also has a growing population and accompanying development. The state has largely effectively targeted protection of many of their most important ecosystems, such as riparian areas and wetlands.

- The information included in this report can be used to provide support for preservation and conservation decisions and help to identify or prioritize high value areas for additional conservation or preservation.

- Although there is an abundance of natural resources within the state, development pressure is also high to meet the ends of a growing population and economy. This places particular importance in using information like ecosystem service assessments to prioritize where growth should be allowed, and which parts of the state are most important to protect as intact ecosystems for the benefit of the rural economy and future generations.

- The implementation of, and use of Ecosystem Services Assessment, is also a consideration for future policy debate which seeks to balance the sometimes competing interests between development and conservation. It can be used as a benchmark for understanding the economic costs of ecological impacts associated with human activities.

Future Work and Next Steps

The work presented in this report represents the first iteration of Maryland's effort to quantify economic benefits from the natural environment. Certain ecosystem services are currently in a preliminary stage and will be added at a later date— mitigation of coastal storm surge, coastal erosion reduction, urban heat island amelioration, and services specific to SAV and oyster beds. The raw data presented here is available on Maryland iMap and the data will be available to view through Maryland GreenPrint in February of 2018. We will continue to update these data as new information on the supply and economic benefits of ecosystem services becomes available.

Photo Credit- Edward Koubeck 2013

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