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Title: Spatial Modeling of the Biophysical and Economic Values of Ecosystem Services in Maryland, USA

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1 Introduction

Ecosystem services (benefits to people derived from ecosystems) vary spatially across the landscape, both in the biophysical supply, often quantified through a benefit relevant indicator (Olander et al. 2015), and in the demand for the service, i.e., the degree to which biophysical supply benefits people, which creates a desire for those benefits (Boyd and Banzhaf 2007). Consideration of both vectors of variability is necessary to understand the spatial variability in ecosystem services, services vital to sustaining humanity's quality of life, if not its existence itself. This is particularly important when the goal is to inform sustainable resource management and land-use planning, with both aspects having implications for the sustainability of the resource. Ecosystem services (ES), in particular those that have economic value not captured in a market, i.e. non-market ES, are not typically included in making the decisions that impact the quality or sustainability of their supply. Many of these decision are made in the province of state government, and our work integrates this value into the state's decision making framework, along with making the information available for use by other levels of government and our partners in the private and non-governmental sectors. In this work we have made an effort to map both the spatial variability in biophysical supply and the economic value of the services across Maryland, USA, with the goal of producing values representative of the benefits that the people of Maryland gain from the natural environment and to inform decision-making by the state government and its citizens. This study maps the benefit relevant indicators and economic values for seven ecosystem services provided by Maryland's ecosystems— carbon sequestration, air pollutant removal, storm-water mitigation and flood prevention, groundwater recharge, surface water protection, wildlife habitat and biodiversity protection, and nitrogen removal.

Many previous studies have mapped ecosystem services (Martínez-Harms et al. 2012, Nelson and Daily, 2012, Nahuelhual et al. 2015), with a great diversity in methodology. Efforts have been made to suggest a standard approach (Bagstad et al. 2013, Crossman et al. 2013, Burkhard and Maes 2017), but it has proved to be a challenge to develop a comprehensive method able to address differences in scale, the services considered, valuation methods, management or policy goals, and data availability. The European Union's Mapping and Assessment of Ecosystems and their Services (MAES) is an ongoing effort to map ecosystem services and report on their values to support policy and decision-making in the EU (Maes et al. 2012). The mapping effort currently presents biophysical values for several services at different scales (EU, National, Sub-national) through an online viewer (BISE 2018). This method is the most common approach to mapping ecosystem services, however, mapping the spatial variability in demand for services over space has proved to be more challenging (Wolff et al. 2015, Ralph-Uwe and Grunwald 2017).

Demand has been quantified through the use of indicators (Muller and Burkhard 2012, Burkhard et al. 2012) or assumed to vary over space according to ecosystem type (Sutton and Costanza 2002, Troy and Wilson 2006, Liu et al. 2011). Quantifying demand is further complicated by the fact that services have different factors that determine the level of demand. Wolff et al. (2015) classify types of demand, such as risk reduction, preferences and values, direct use or consumption of goods and services. This is influenced by the scale at which the demand, or benefit, occurs. For instance, the benefit component of the carbon sequestration ecosystem service comes from the reduction of risk due to climate change, experienced at the global scale, compared to the service of flood prevention where the demand is due to lower risk of flood damage at the watershed scale. Grêt-Regamey et al. 2014 explored the effect of scale and data resolution on mapping ecosystem services and Grêt-Regamey et al. 2015 present a tiered approach for modeling spatial ecosystem services centered on mapping an ecosystem service to answer a particular research or policy question.

Mapping of ecosystem services in a comprehensive way for both benefit relevant indicators and economic value, has not been done for a US state. The InVEST suite of tools (Natural Capital Project, 2012) could theoretically be used to generate similar spatial data for benefit relevant indicators and economic value estimates, but we are not aware of this method being applied to an entire state and the results made available for public use. Many maps of ecological functions exist, and some maps of benefit relevant indicators (Ingraham and Foster 2008, EnviroAtlas- Pickard et al. 2015, LandScope- NaturServe 2018) but, to our knowledge, never have these maps been translated to economic values and made publicly available. The State of Delaware funded an ecosystem service assessment of their state (Kauffman et al. 2011, IEC, 2011), as did New Jersey (NJ DEP 2007) but the results are not available to view spatially outside of the reports.

1.1 Economic Valuation

We use the eco-price method (Campbell and Tilley 2014, Campbell 2018) to estimate the monetary value of ecosystem services. The eco-price is defined as the ratio of the dollar amount that has been paid to preserve or restore an ecosystem service, or costs avoided due to the ecosystem services ascribed benefit, to the change in ecological function, where the dollar amounts are based on current trends observed in society’s payment for and valuation of these services. This is necessary because these services largely exist outside of traditional markets. The eco-price reconciles the biophysical value of the environment with its 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. 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 gains from the work of the environment, it is not necessarily equivalent to the market value of those services, and the values presented here are not meant to imply market values. The social values presented here are intended to be used to inform decision making and quantify trade-offs, rather than market exchanges. The ecosystem service values presented here are currently being used by the Maryland Department of Natural Resources as support for state land conservation acquisitions, a policy is being written for using lost ES value as suggested compensatory value for impacts on state owned lands, and we are in the process of incorporating ES value into our ecological restoration funding selection process. The spatial ES information is available through a public web viewer, geodata.md.gov/greenprint/ and the Maryland imap data delivery service, imap.md.gov.

1.2 Study Area

The State of Maryland is known for its physiographic diversity and it has been referred to as Little America or America in Miniature due to its 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. Going from east to west the physiographic regions are the Coastal Plain Province, the Piedmont Plateau Province, the Blue Ridge Province, the Ridge and Valley Province, and the Appalachian Plateau Province (Edwards 1981). The majority of the state is at a relatively low elevation; the average elevation is only 106 m above sea level, with the average elevation increases from east to west. The state of Maryland is 40% forested, with forest covering 2.7 million acres of land (MD DNR 2010, Rider 2005). Seventy six percent (76%) of forest land in Maryland is privately owned. Maryland contains 342,626 acres of freshwater wetlands, with the vast majority (>99%) classified as palustrine; the remaining small percentage of freshwater wetlands in the state is riverine or lacustrine. Estuarine wetlands in Maryland predominately occur in the Chesapeake Bay and its tributaries, although the Coastal Bays on the Atlantic coast also contain coastal wetlands, and cover 251,542 acres of the state (Tiner and Burke 1995, Clearwater et al. 2000, MDE accessed 2016). Maryland has developed rapidly over the last 40 years and is now the 5th most densely populated state (Homer et al. 2015). Development impacts the supply of ecosystem services, reducing the natural capital of the state (Breunig 2003). In the case of certain services, like air quality and flood prevention, an increasing population also increases the demand for the service.

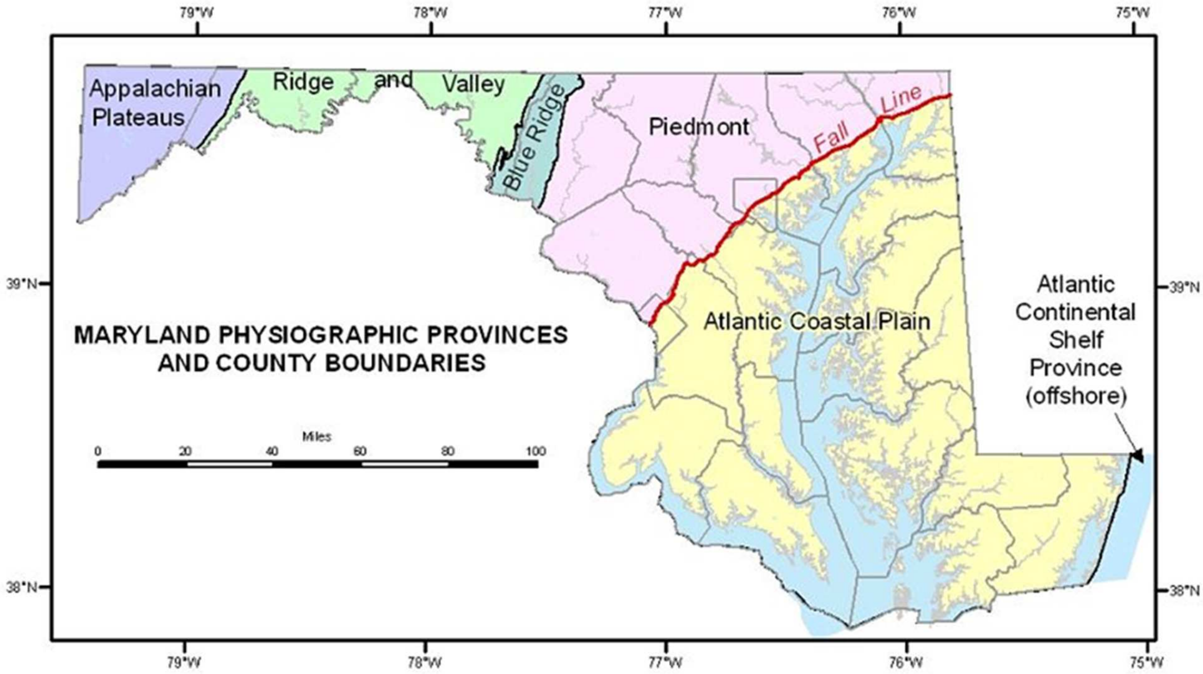

Figure 1. Physiographic regions in Maryland. Image from Maryland Geological Survey.

2. Methodology

2.1 Selection of Ecosystem Services for Evaluation

For the purposes of this study, we define ecosystem services as 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, 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) (Campbell, 2018). 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 benefit relevant indicator for each service spatially across the studied ecosystem. This was done through development or adoption of models for each service in the State of Maryland (see below for individual services).

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. Sum individual ecosystem service values to find the sum economic value of the ecosystem services provided by the system considered in this analysis.

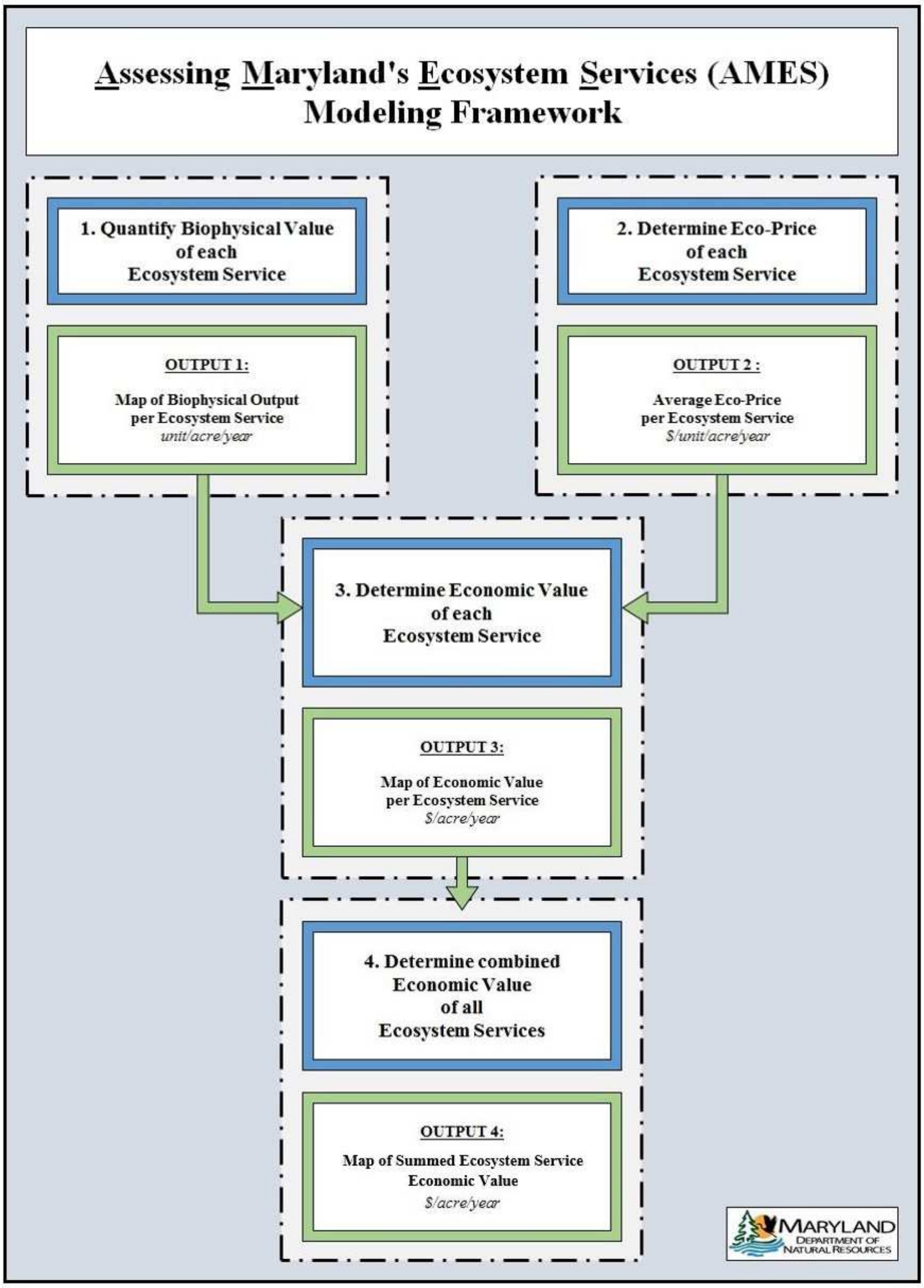

Figure 2. Workflow for Accounting for Maryland’s Ecosystem Services (AMES) modeling framework

2.2 Mapping Individual Ecosystem Services

2.2.1 Land Cover Extent

In this study, ecosystem service mapping is focused on forest and wetland areas across the state of Maryland. Forest extent across Maryland was represented using NASA/ UMD Carbon Monitoring System Tree Canopy layer (Hurtt 2016). This raster data layer was created using a combination of LIDAR and NAIP aerial imagery, and provides the meters squared area of tree canopy per 30m pixel. Wetland extent across Maryland was represented using a unification of the National Wetland Inventory (USFWS 2016) and DNR wetland inventory (MD DNR 1995). Wetland polygons were converted to a 30m raster layer, which provided the meters squared area of wetland per 30m pixel.

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, existing external ecological models are leveraged, while other services are modeled internally using a combination of GIS data inputs and published ecological thresholds. Each ecosystem service specific model produces a per-pixel (30 m) estimate of the amount of biophysical output produced by a given service across the state. The economic value for each ecosystem service is calculated using the eco-price (Campbell 2018), applying a price per biophysical unit to the spatial trend of said biophysical unit. For services where an index is used to quantify the spatial trend an estimate is made of the biophysical quantity corresponding to each level of the index. While each service relies on the same forest and wetland extent coverage for the state, the extent of where data exists within those boundaries varies with the biophysical ecosystem service model considered. For this reason, the area of forest and wetlands with ES results is slightly different for each service (see Table 6).

2.2.2 Carbon Sequestration

The rate and amount of carbon sequestration within forests and wetlands varies spatially across Maryland, as a result of various environmental gradients. The primary sources of variation in forests are species composition and tree age. Wood density, and thus the density of carbon stored, varies with tree species, with deciduous trees such as oaks and hickories storing more carbon than do evergreen trees such as pines and hemlocks. Further, carbon sequestration rates increase exponentially in the first 30 years of a tree growth, followed by a slowing and plateauing of sequestration as trees reach maturity. Carbon sequestration rates in forests across the state, including deciduous forests, evergreen forests, mixed forest, and shrub-land were derived from the USFS i-tree landscape online tool (USFS 2017). Climate and site specific factors such as soil type are also factored into the model. For this process we applied USFS i-Tree Landscape carbon sequestration coefficients at the Census block group level to updated % tree canopy extent data. A model of net carbon sequestration in wetland areas across the state of Maryland was developed. The model incorporates the spatial variability of both the rate and amount of carbon sequestration and methane emissions within wetlands across Maryland, by wetland type and along a gradient of water salinity. Average rates of carbon sequestration and methane emissions across different wetland types (estuarine and palustrine) and salinity types (fresh, oligohaline, mesohaline) were derived based on field data for the Chesapeake Bay region published in the scientific literature. (121 and 34 sites, respectively). Carbon sequestration from forests, derived from the i-Tree Landscape model, and net sequestration from wetlands, was then combined in order to map net GHG emissions from natural land based sources across Maryland.

Wetland extent was delineated using a NWI and 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 by freshwater wetlands, with C sequestration decreasing as the salinity of the water increases.

We use the Social Cost of Carbon (IWGSCC 2013) calculation, the federal standard established by the US EPA as an estimate of the costs of climate change, and to value carbon sequestration in Maryland. We used $143 per MT of carbon, the mid-point of the Social Cost of Carbon, in this work.

Table 1. 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
Verified Carbon Standard (VCS) Average (RAE 2015)			1.46	

Table 2. Methane emission rates by salinity class

Salinity Class	***N Sites***	***Mean*** (MT ha^{-1}yr^{-1})	***CO$_2$ 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*

2.2.3 Air Pollutant Removal

Trees remove more air pollutants with a greater impact on human health in urban areas than elsewhere. Nowak et al. (2014) 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 from lowered pollutants 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 modeling of the removal of air pollutants by trees (see Figure 13) and what would be the resulting expected health costs of the removed pollutants (accomplished through the BenMap model- USEPA 2012). 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, as assessed by the US EPA. Urban areas are defined as having a population density greater than 2,500 people in the census area. i-Tree Landscape models the uptake of 6 atmospheric pollutants— Carbon Monoxide (CO), Nitrogen Dioxide (NO2), Sulfur Dioxide (SO2), Ozone (O3), Particulate Matter 10 (PM 10), Particulate Matter 2.5 (PM 2.5). USFS i-Tree Landscape pollution removal coefficients were applied at the Census block group level to updated % tree canopy extent data. We use the economic impact that air pollution removal has on health costs. Removal rates of air pollutants and resulting economic values are summarized in Table 3.

Table 3. Eco-prices used to calculate the air pollution removal as an 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
PM2.5	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
Sum	**108,632,429.56**	**$149,228,585.17**	**$1.37**
Area (m2)	25,630,890,300.00	-	-
Canopy (m2)	12,520,784,221.45	-	-

2.2.4 Wildlife Habitat and Biodiversity

We considered the size of the habitat, the degree of connection to other habitats (scored through the MD Green Infrastructure model, MD DNR 2003), and the presence of rare species or habitats (scored through the MD BioNet model, MD DNR 2016), when calculating the wildlife habitat and biodiversity ecosystem service index (a 1-100 ranking). This creates an index which considers both the quality of wildlife habitat to support species movement and the potential for the habitat to support biodiversity (i.e. rare or threatened species). Land in the Green Infrastructure model was assigned to quintiles based upon their score, and then assigned values (1 to 5) corresponding to the quintiles. Land in the top two ranks of MD BioNet was assigned to the 1st and 2nd quintiles of value, respectively. Forests and wetlands occurring outside both models were given the lowest quintile value. Figure 6 displays the Wildlife Habitat and Biodiversity Index across Maryland.

The value of habitat for rare and threatened species as characterized by the price paid for habitat banking[1] or it was assumed to be the maximum value, assigned to Tier 1 and 2 of the MD BioNet modified by the 100 values of the Green Infrastructure score. The MD BioNet values scale 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).

2.2.5 Stormwater Runoff and Flood Prevention

Several factors determine the amount of stormwater runoff that is stored on the landscape; the type of soil, presence of a floodplain, whether it is in a riparian area, the type of wetland, and the impervious surface percentage of the surrounding watershed (Joyce and Scott 2005). All of these characteristics factor into how much water runs off into the area and the ability of the area to absorb that water. All of these characteristics were considered when ranking the ability of forests and wetlands in Maryland to reduce stormwater runoff. Generally, riparian areas, forests and wetlands in watersheds with high impervious area upstream receive larger amounts of stormwater runoff and were ranked the highest (5) in our 1-5 index. This rank was related to the stormwater ecosystem service by observing the range of stormwater volumes treated by forests or wetlands.

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[1] Habitat banks, or conservation banks, are parcels of land containing natural resource value that are conserved and managed in perpetuity for specified listed species and used to offset impacts occurring elsewhere to the same resource values.

A modified version of the Watershed Resource Registry Stormwater Preservation model (WRR 2016) was used to rank the relative capacity and stormwater load across the landscape from 1-5 (figure 8). 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 (MDE and CWP 2009) and the Virginia Stormwater Management Handbook (VA DEQ 2013) to estimate the range of stormwater volumes treated in forests and wetlands. Table 4 displays the depth of stormwater treated attributed to the ranking for forests and for wetlands. We considered multiple ways people pay for mitigating stormwater and preventing flooding, e.g., stormwater remediation fees (MDE 2014) and numerous other cost estimates (King and Hagan 2011), and the benefits forests and wetlands have in reducing flood insurance premiums (MD DNR 2018). This results in an average value of \$0.33 per m^3 of stormwater reduced.

Table 4. 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

2.2.6 Groundwater Recharge

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 (USGS, 2016) is the data source on which we rely for our assessment. We used the "Estimated Mean Annual Natural Groundwater Recharge, 2002" for the mid-Atlantic region.

This layer was specifically created to estimate the mean annual natural groundwater recharge, in millimeters, per watershed catchment segment in the application of the national SPAtially Referenced Regression On Watershed attributes (SPARROW) model. The groundwater estimates at the in cm3 per m2 were then converted to m^3 per 30m pixel to arrive at our biophysical estimate of the service. The underlying geology across the landscape is the primary driver of the rate that water enters unconfined and confined aquifers at the landscape scale. The amount of impervious surface and soil condition also affect the amount of water reaching aquifers.

In assessing the value of groundwater recharge in Maryland we considered the average municipal price of water in Maryland (WSSC 2016), the value of water for recreation (Reardon 2007, Roland 2007), and the cost of investment in watershed protection (NY DEC 2016). These values average \$0.35 per m^3 water (Campbell 2018).

2.2.7 Surface Water Protection

Approximately half of the water supply in Maryland is sourced from reservoirs. Natural lands reduce the cost to treat water from reservoirs to water supply standards through reducing loading of sediment and other pollutants to the waterbody. 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. For smaller sources, it was more difficult to quantify the amount of water being supplied and the economic benefit of the forests in the watershed on the water source. The five major reservoirs in Maryland that we considered here are Loch Raven, Liberty, Pretty Boy, Tridelphia, and Rocky Gorge. We used a different value for the surface water protection eco-price than ground or stormwater, averaging cost savings of water treatment from having trees in the watershed (Riley 2009, Elias et al. 2013), the municipal price of water (WSSC 2016), and the cost avoided by not having to upgrade a treatment plant to advanced treatment (HDR 2013, Warziniack et al. 2016US); these average \$1.52 per m^3 of water.

2.2.8 Nitrogen Removal

Forests and wetlands in watersheds with high amounts of urban or agricultural land-uses receive and take-higher quantities of nutrients, resulting in higher uptake rates. Forests and wetlands have a finite ability to take up nutrient inputs and several 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). We focused on nitrogen removal rather than phosphorus, because there is a greater depth in the literature on nitrogen removal rates, and more evidence for an eco-price in Maryland for nitrogen. It was found through literature review 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 (Merrill & Cornwell 2000, Thomas & Christian 2001, Kemp 2006). Freshwater wetlands in the floodplain process and store higher quantities of nitrogen than isolated wetlands (Chesapeake Bay Program (CBP)+ 2008).

The USGS SPARROW (Spatially Referenced Regression on Watershed Attributes, Ator et al. 2011) 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. Using SPARROW incremental loading rates (the amount of nitrogen input within each catchment that reaches the nearest waterway), we calculated the amount of nitrogen taken up by the landscape within that catchment. Nutrient uptake rates were then used to assign low, medium, and high values (Figure 13) 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 5.

We value nitrogen removal by observing the average cost to remove nutrients using best management practices, what the state provides for the BMP cost share program (MDA 2015) and through the Bay Restoration Fund (MDE 2015), and the price on nutrient trading markets (PA DEP 2015). This averages $18.34 per kg nitrogen (Campbell 2018).

3. Results

3.1 Carbon Sequestration

Carbon sequestration rates for deciduous, evergreen, mixed forest, and shrubland were taken from the USF'S i-tree landscape online tool (USDA-USFS 2016) and ranged from 0.4 Mt per ha to 3 Mt per ha, excepting outlier values. For wetlands we accounted for the net GHG impact of the land type by accounting for methane emissions, although above a salinity of 18‰, methane emissions are typically negligible (see Table 2). Sequestration rates for both forest and wetland areas are summarized in Table 1.

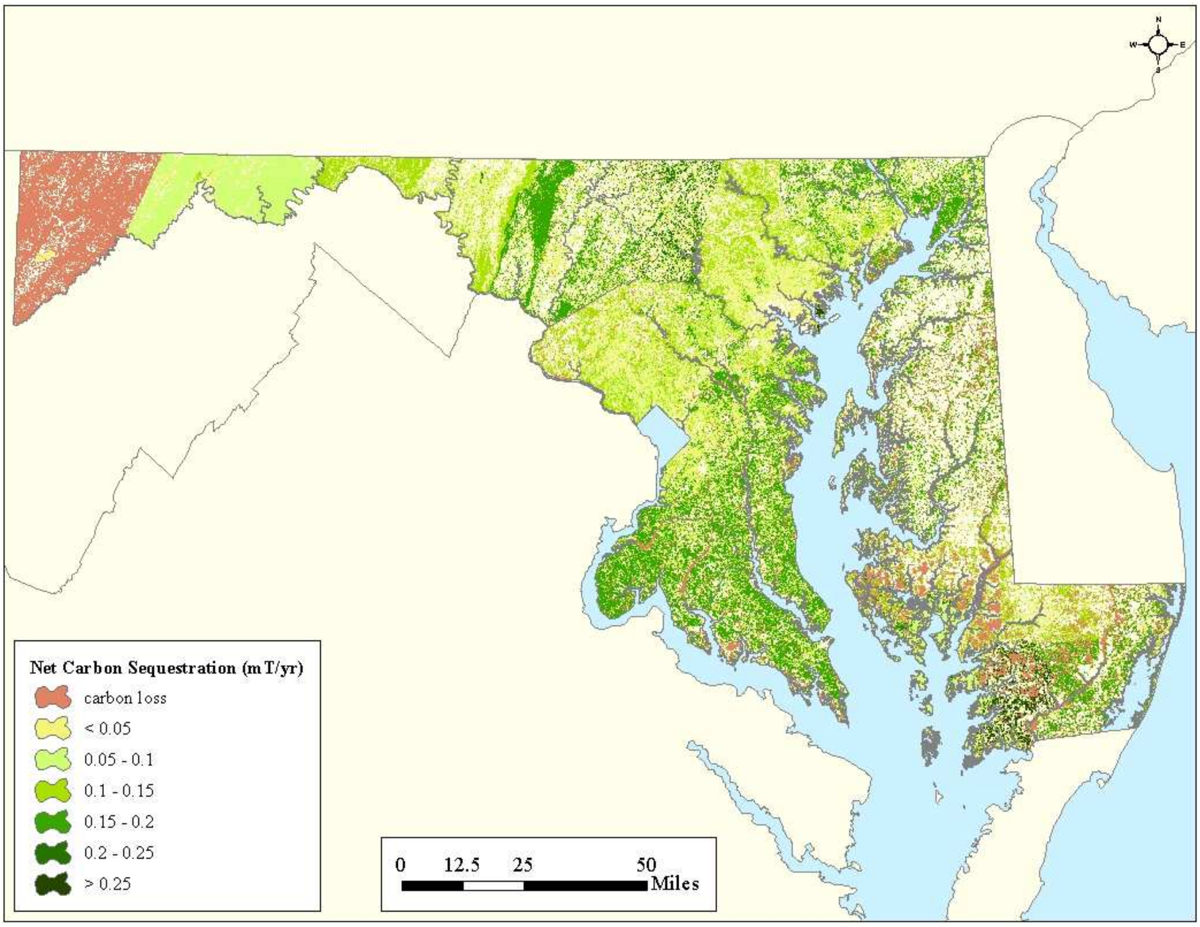

Figure 3. Carbon sequestration MT net CO_2e) in forests and wetlands across Maryland. Value per 30m pixel.

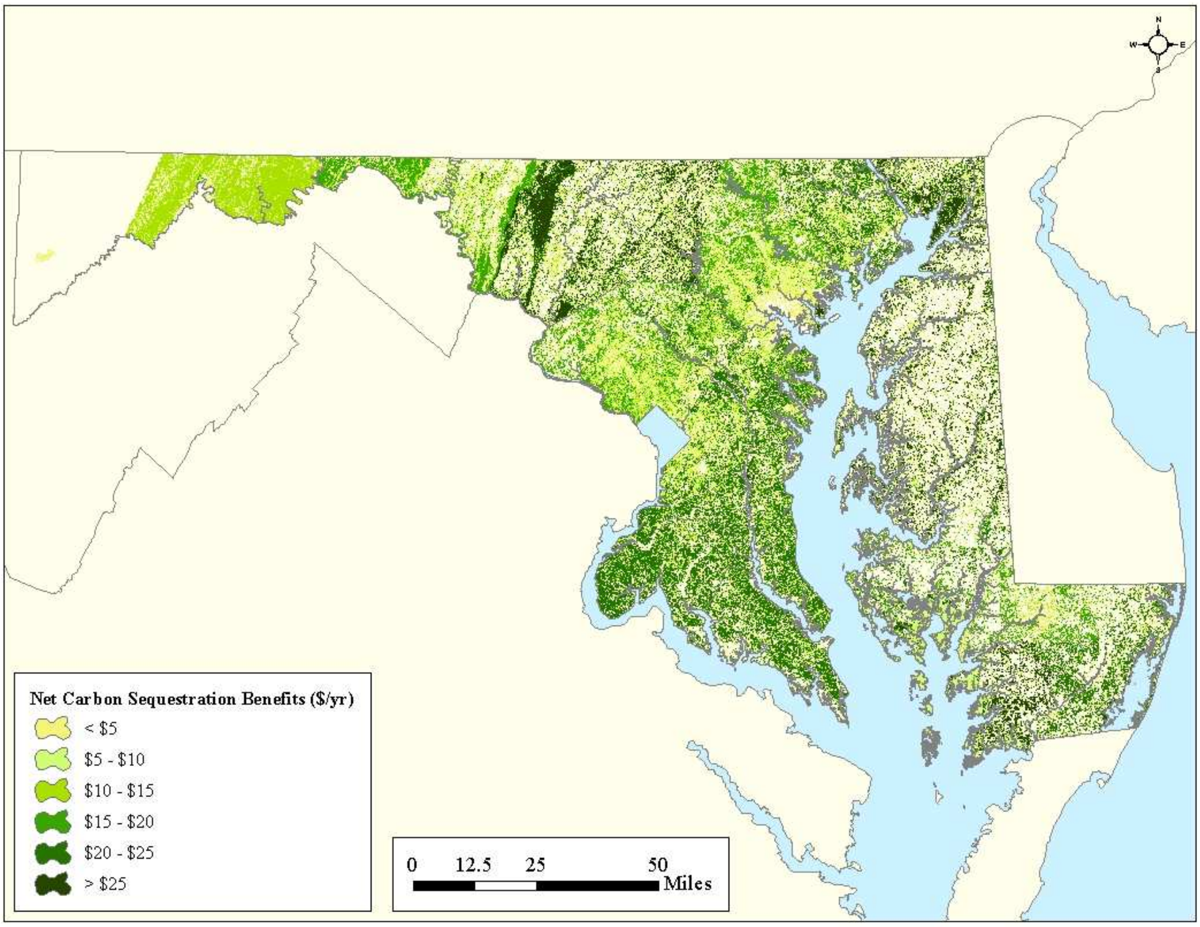

Figure 4. Economic value of carbon sequestration by forests and wetlands in Maryland, positive GHG emissions given a value of $0. Value per 30m pixel.

3.2 Air Pollution Removal

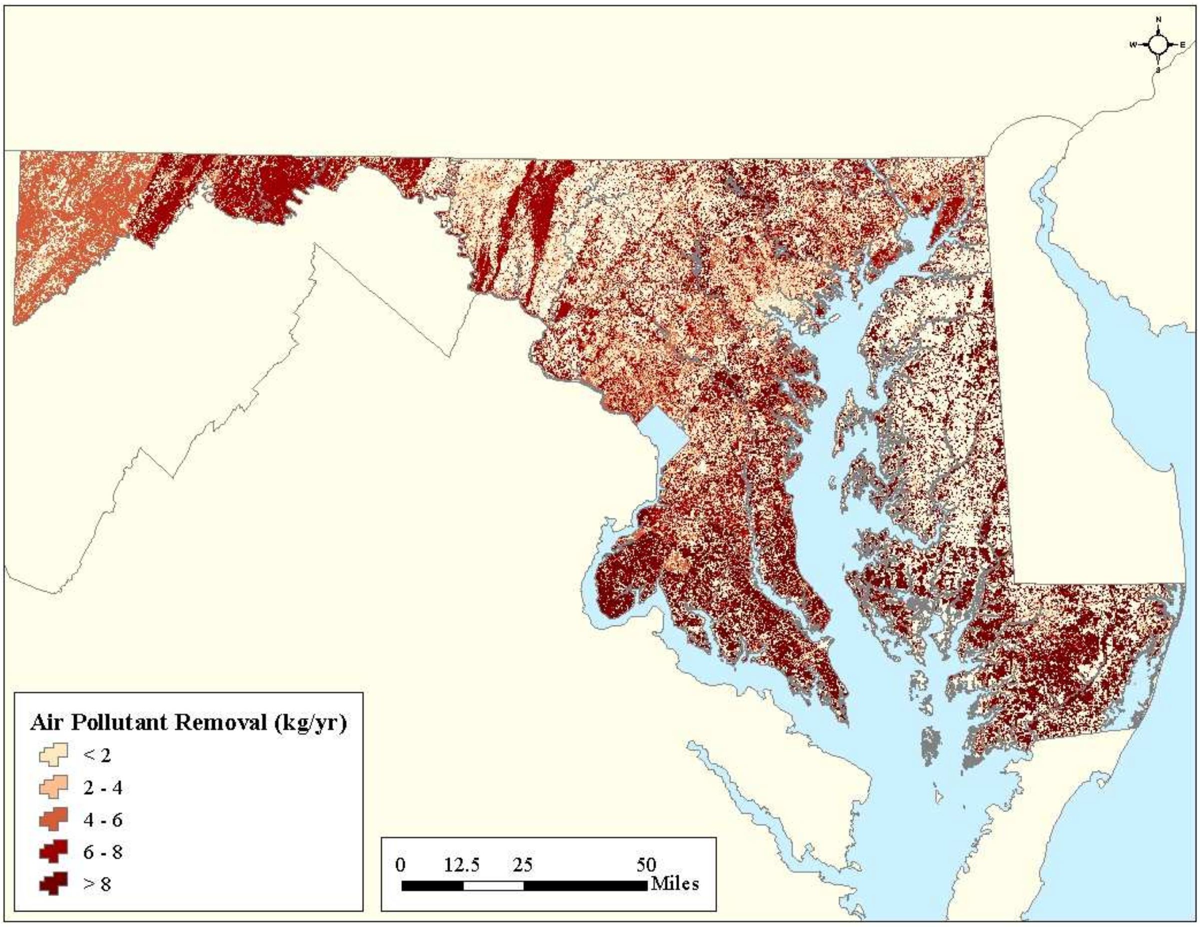

Figure 5. Mass of air pollutants (sum of the six considered here) removed by the tree canopy across Maryland. Value per 30m pixel.

The spatial distribution of air pollutant removal and associated economic values across Maryland is illustrated in figures 4 and 5, respectively. 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.

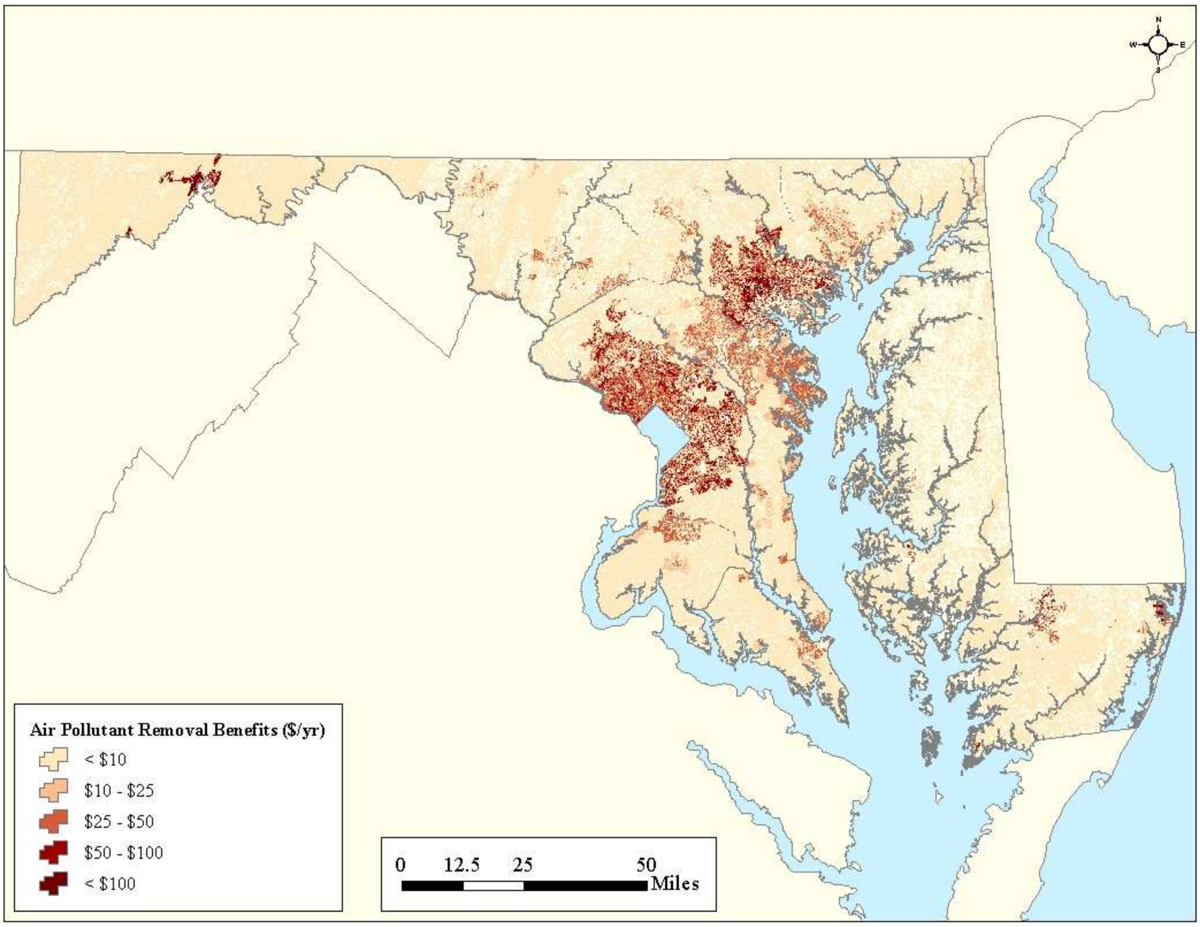

Figure 6. Economic value of air pollutants reduced by the tree canopy in Maryland, per 30m pixel.

3.3 Wildlife Habitat and Biodiversity

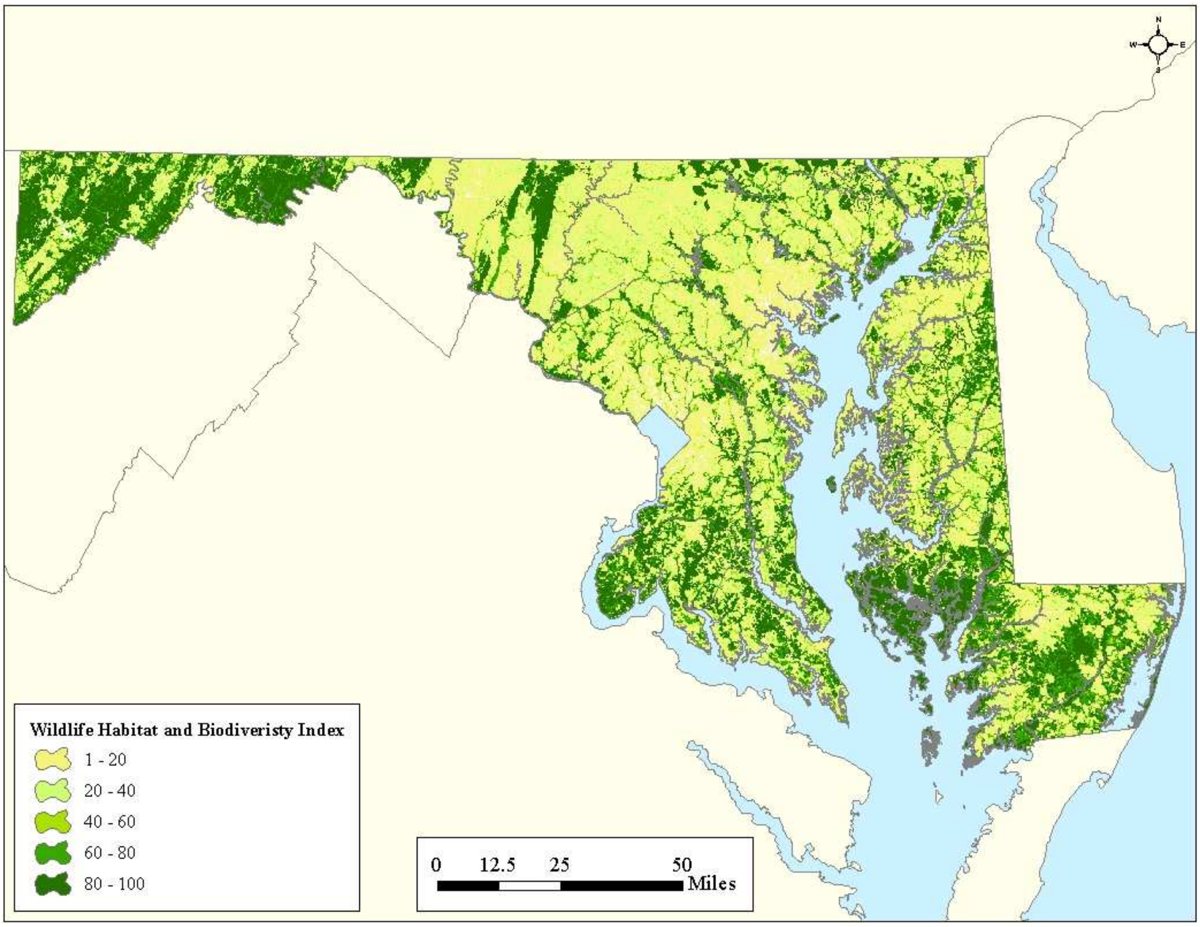

Figure 7. Index of Wildlife Habitat and Biodiversity (1-100, 100 being higher quality habitat)

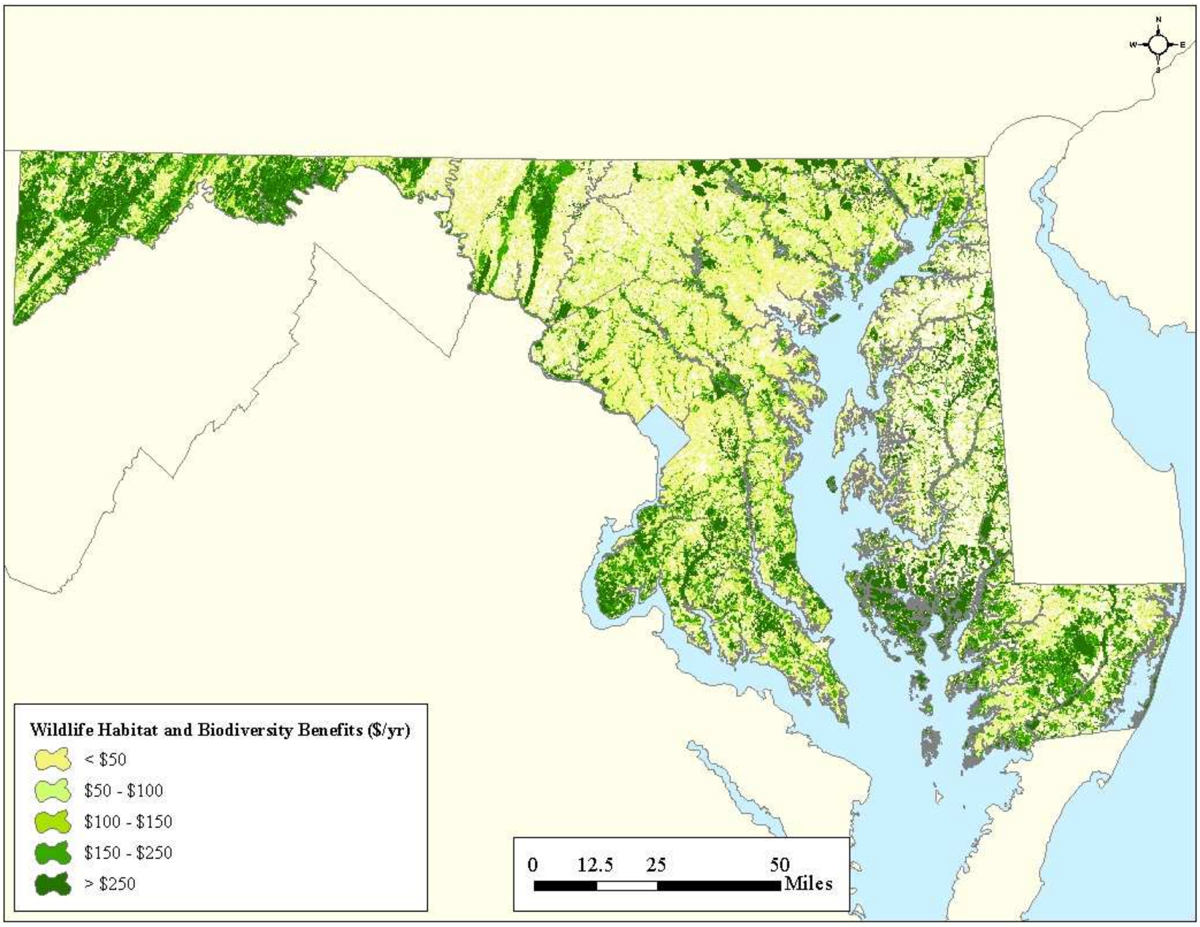

Figure 8. Economic value of wildlife habitat and biodiversity across Maryland, per 30m pixel.

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3.4 Stormwater Runoff and Flood Prevention

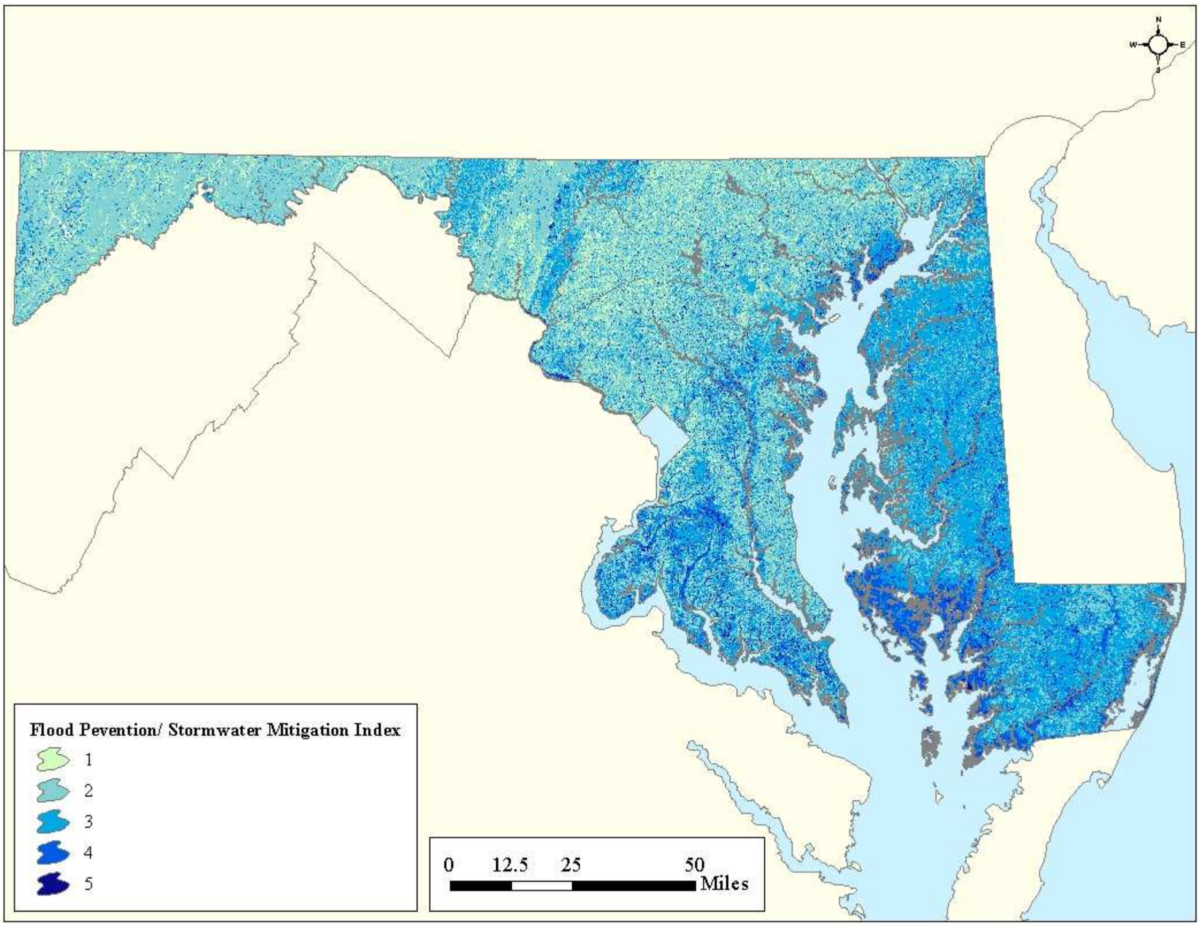

Figure 9. Index of flood prevention/stormwater mitigation across Maryland

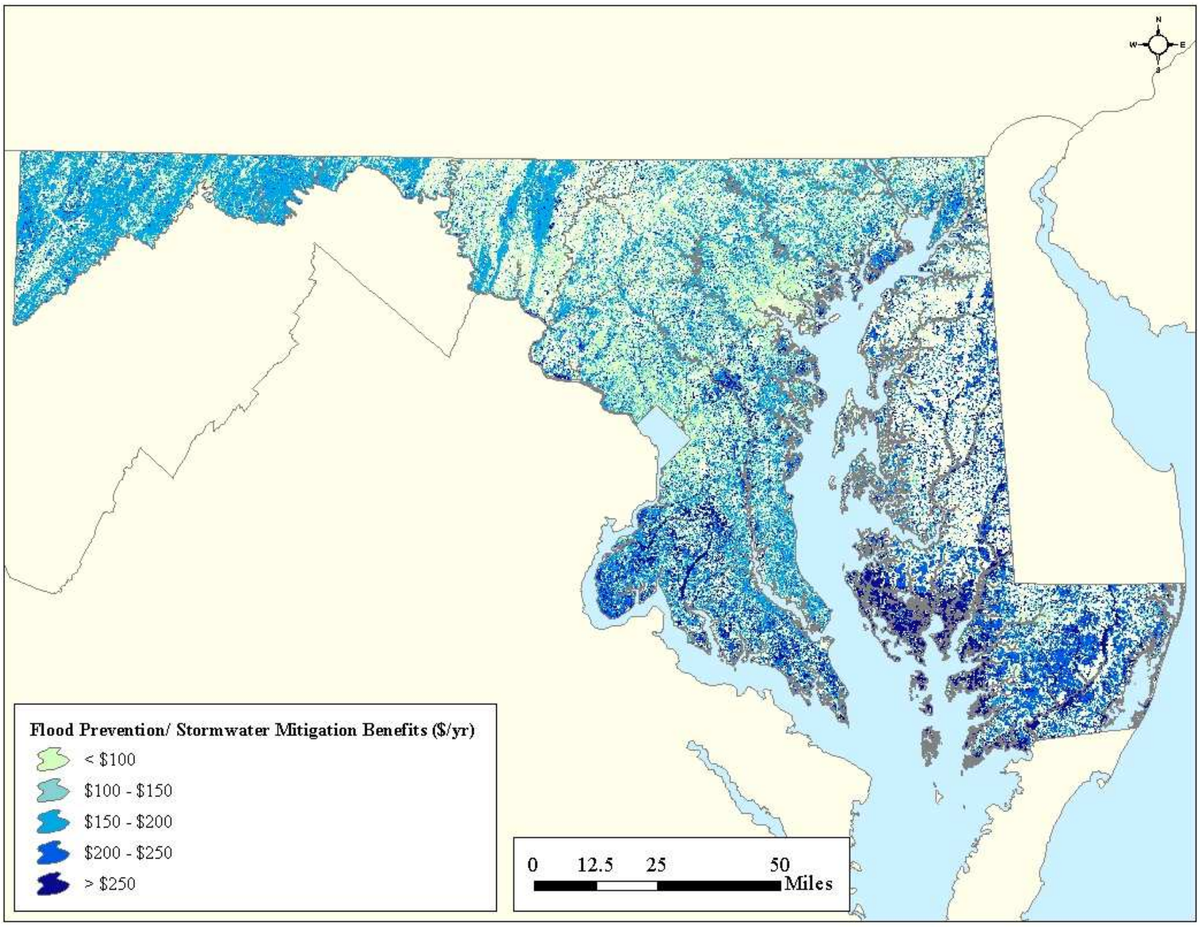

Figure 10. Economic value of flood prevention/stormwater mitigation ecosystem service across Maryland per 30m pixel.

3.5 Groundwater Recharge

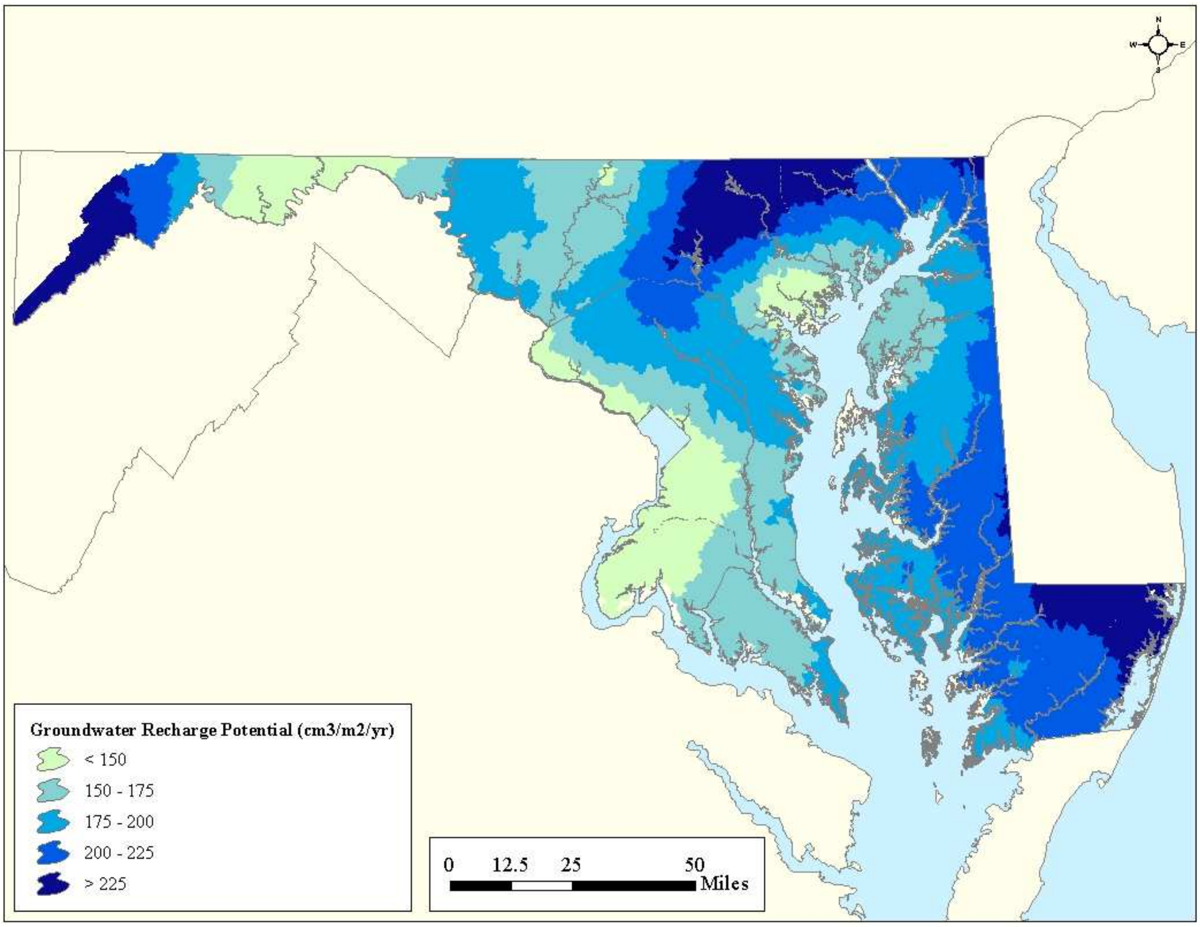

Figure 11. Groundwater recharge across Maryland

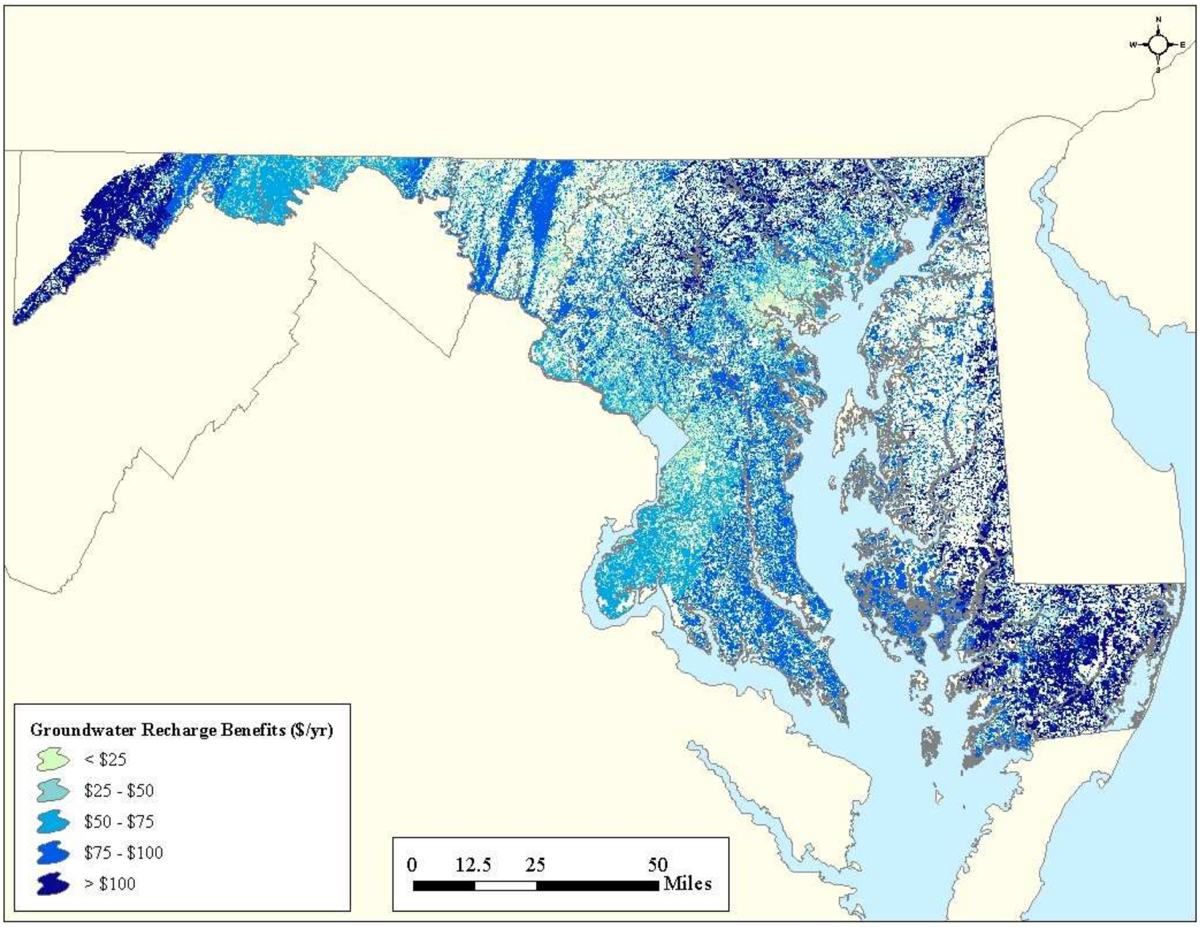

Figure 12. Economic value of groundwater recharge in Maryland per 30 m pixel.

3.6 Surface Water Protection

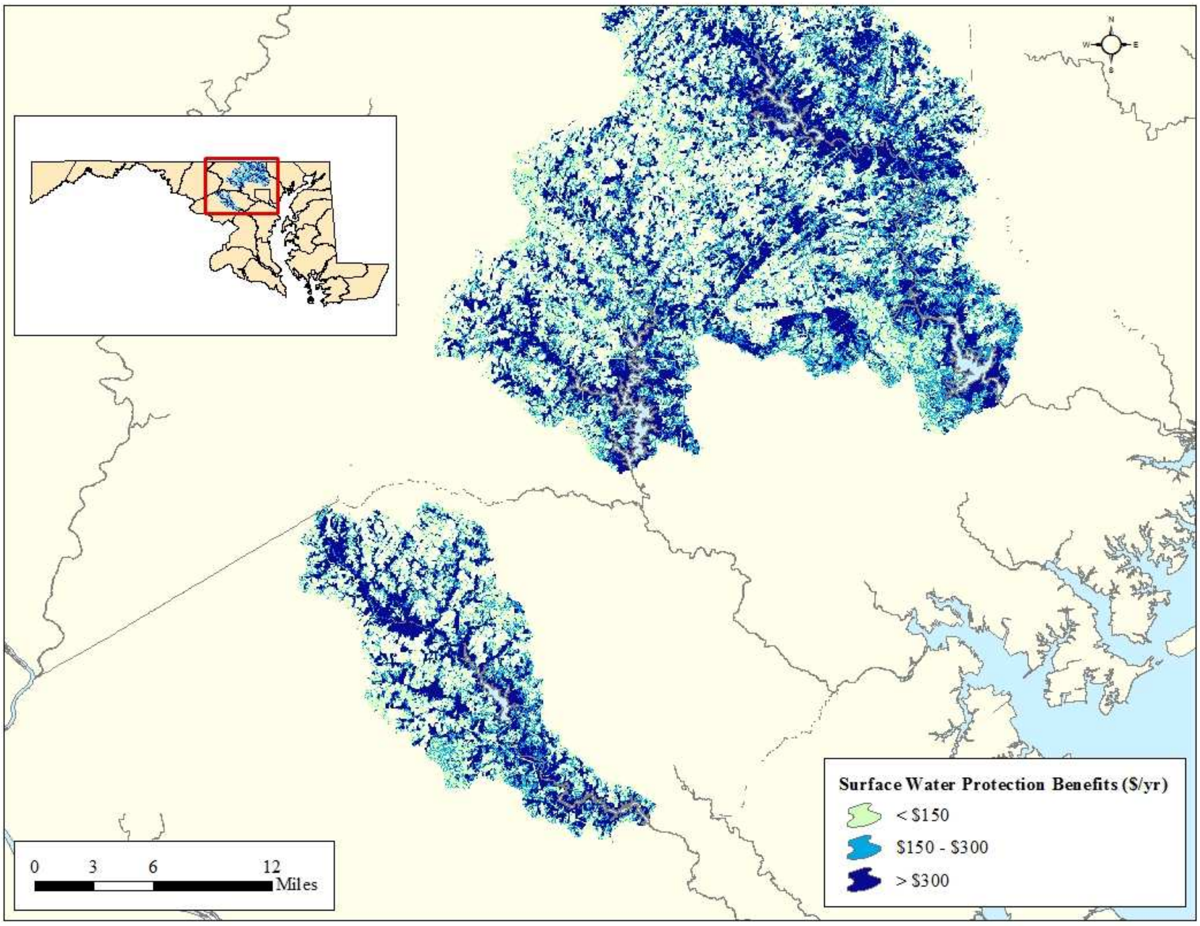

Figure 13. Economic value of surface water protection in Maryland per 30m pixel.

Table 5. Nitrogen removal rates for forests and wetlands in Maryland in High, Medium, and Low N Loading Watersheds

Ecosystem Type	Nitrogen Removal Rate	Reference
	kg/ha/yr	
Forest		
Low N Loading Watershed	5	CBP 2008
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
Brackish (2.5-18 ppt)	300	Merrill & Cornwell 2000, Kemp 2006
Salt (18+ ppt)	900	Thomas & Christian 2001

3.7 Nitrogen Removal

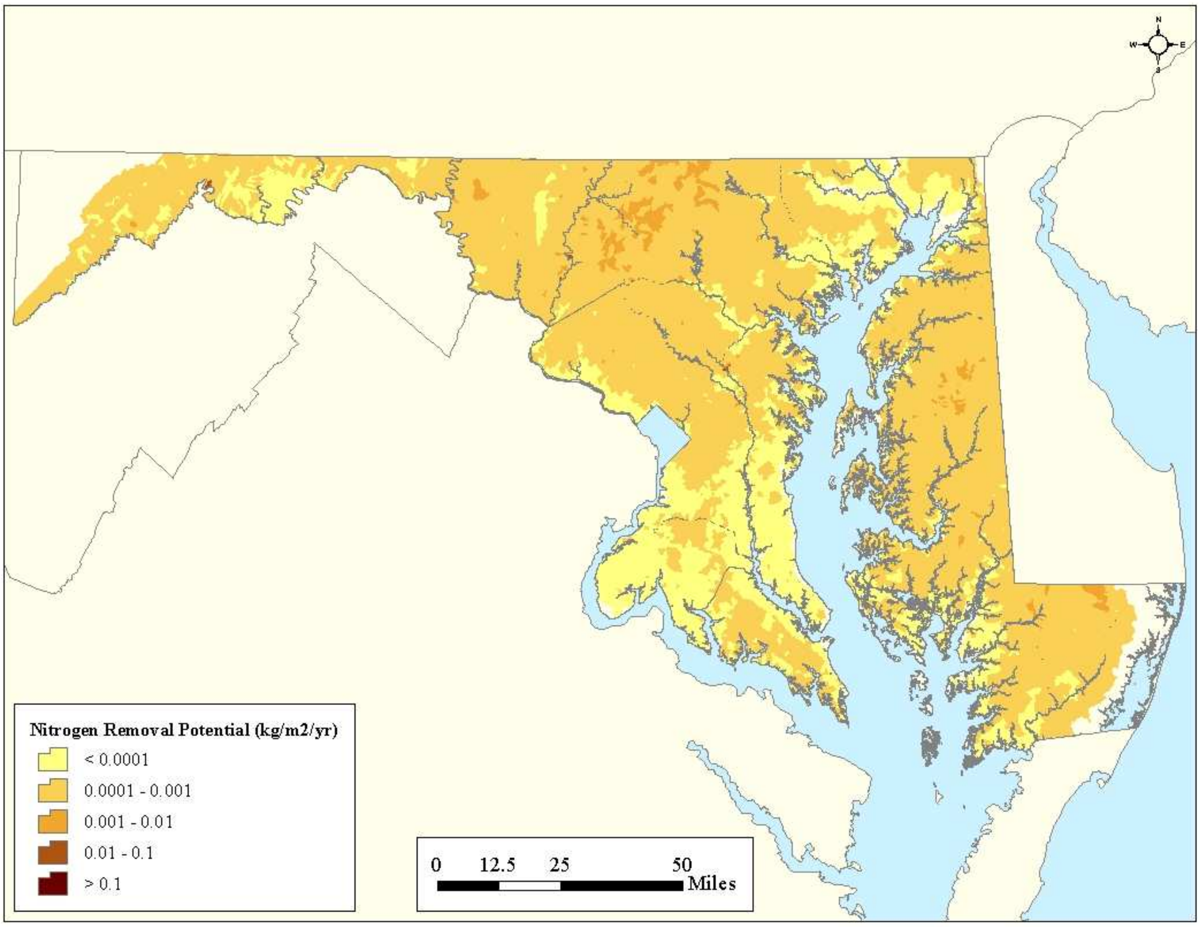

Figure 14. Potential for removing nitrogen across Maryland

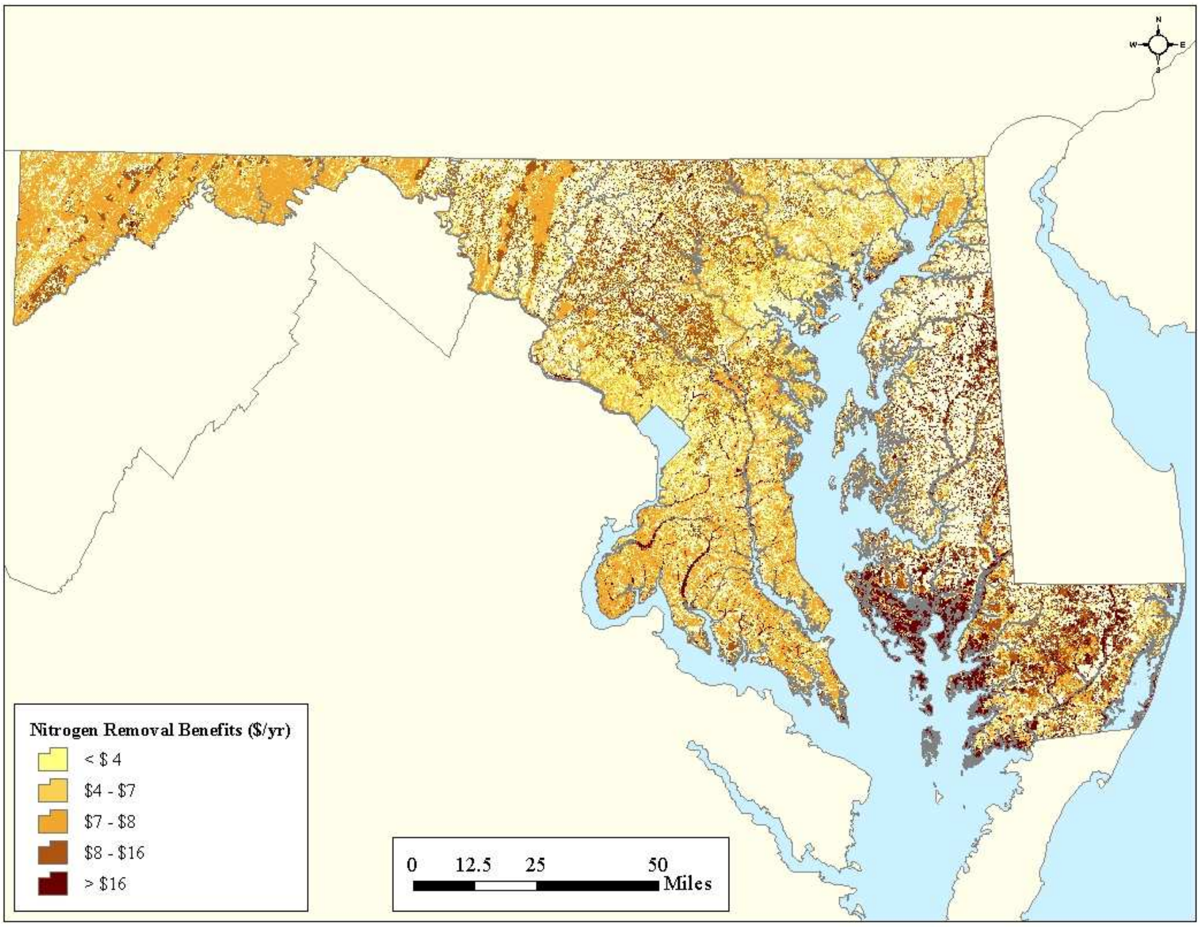

Figure 15. Economic value of nitrogen removal ecosystem service across Maryland per 30m pixel.

3.8 Sum of Ecosystem Service Values

Table 6. Summary of Ecosystem Services

	Biophysical		**Economic**		**Area (ha)**
Ecosystem Service (biophysical unit)	**Average (30m)**	**Sum**	**Average (30m)**	**Sum**	
Air Pollution Removal (kg yr-1)	5.46	108,835,576	$7.19	$143,320,944	1,794,996
Carbon Sequestration (MT yr-1)	0.10	1,721,227	$13.80	$239,662,362	1,883,559
Groundwater Recharge Potential (cm^2 m^{-2} yr^{-1})	185.49	na	$66.59	$1,261,936,554	1,705,580
Nitrogen Removal Potential (kg m2 yr-1)	0.000014	na	$21.05	$416,960,289	1,782,790
Stormwater and Flood Mitigation (1=low, 5 = high)	2.56	na	$153.33	$3,116,716,266	1,829,363
Wildlife Biodiversity and Habitat (1=low, 100 = high)	44.89	na	$132.83	$2,648,167,790	1,794,324
Surface Water Protection (1=low, 5 = high)	na	na	$198.84	$247,344,710	111,956
Sum of Ecosystem Services	na	na	$375.46	$8,029,887,859	1,924,835

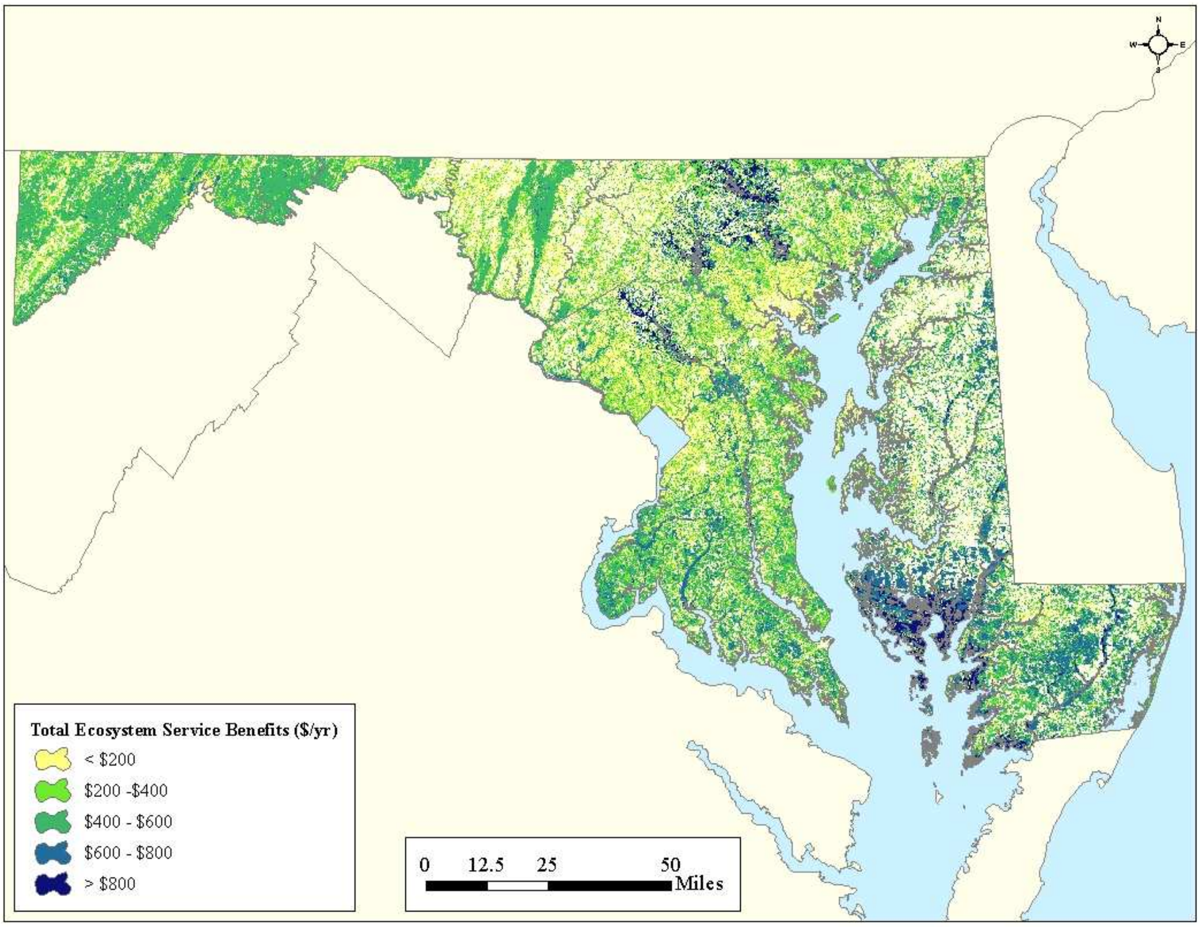

Figure 16. Sum of the economic value of all seven non-market ecosystem services across Maryland per 30m pixel.

3.9 Spatial Distribution of Ecosystem Service Value

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 $6,482 per ha, forested terrestrial wetlands averaged $5,664 per acre and forests averaged $3,820 per acre of benefits supplied every year. In sum, 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 $14,371 per acre per year, however this confluence of high value ecosystem services was rare, the common maximum value observed was ~$11,120 $ per acre per year.

4. Discussion

There are many implications and potential applications of the ecosystem services assessment of Maryland. This analysis is unique in comparison to previous ecosystem service mapping efforts, in that both supply of the service and demand are mapped at a high resolution (30 m), a relatively comprehensive set of services are considered, and there is a clear path to the application and implementation of results into both governmental and non-governmental decision-making. Optimal ecosystem service value can be used when deciding how municipalities or counties meet stormwater or nutrient reduction goals, allowing full cost-benefit comparison of green and grey infrastructure alternatives. Return on investment (ROI) is a commonly used economic metric to evaluate the net benefit of making an investment and ecosystem service values based on this assessment 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. It should be noted that the values presented here are only for non-market ecosystem services with sufficient available spatial data for biophysical mensuration or indication and economic valuation. Provisioning services like timber or recreational services like hunting and fishing, have significant value for the state and should be considered in decision making as well. These values have been estimated previously (US DOI 2011, Ferris and Lynch 2013, Guy et al. 2017) and could be incorporated into a decision-making framework. The following sections detail examples where the results of this study could be influential in decision making specific to the State of Maryland.

4.1 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 (MD DNR 2018) and several outreach events have been conducted with the Maryland land trust and local planning communities.

4.2 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.

4.3 Planned: Restoration Return on Investment

Comparison of the cost of implementing certain programs to the increase in ecosystem services through expanding or restoring natural lands (e.g. reforestation, wetland restoration) is a potentially important application of this analysis. The addition of ecosystem service value allows benefits of restoring natural lands to be realized, beyond complying with state or federal law, potentially further incentivizing restoration of degraded lands. Restoration activities are most appropriate in more impacted regions where the benefit of increasing ecosystem services like stormwater mitigation and nutrient removal will be higher. This application is planned for evaluating restoration opportunities through the DNR and its ecological restoration funding programs.

4.4 Planned: Regulatory Return on Investment

Results of this work indicate that regulations like Critical Area (COMAR Title 27) 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, which can prohibit or restrict development, or direct resources towards certain priority areas. Existing programs to protect lands in Maryland 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 forest and wetlands have an average value of $6,178 of ecosystem services per ha, compared to $4,243 per ha for all natural lands in the state. The additional value of protected lands is likely due to a combination of higher value lands being targeted for acquisition and protected lands being better managed. 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 allow tradeoffs in enabling vs. restricting development to be made, likely leading to additional investment in preservation and restoration and better targeting for expenditure of existing dollars.

4.5 Transferability of the Approach

If similar data on biophysical trends and economic preference is available for other geographic regions these results could be replicated there. Some of the underlying biophysical data utilized in our models is available for the entire continental United States (air pollution, carbon sequestration by forests, groundwater recharge), other data is regionally available (nitrogen removal, stormwater/flood prevention index), while the remaining data (wildlife habitat and biodiversity index, surface water protection index) is only available in Maryland. The economic preference estimates (i.e. eco-prices) are specific to Maryland or the surrounding states and would need to be calculated for the region of interest.

4.6 Double Counting

The potential for double counting is mitigated in this analysis by considering the multiple ways that society pays for different ecosystem services collectively, 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 (Ducks Unlimited 2014). 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 or water quality improvements on a land that is conserved, independent of what was paid to conserve the land for wildlife habitat.

4.7 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 (Ingwersen 2010). The underlying models of the benefit relevant indicators have different degrees of uncertainty; however, this has not been quantified. For many of the ecosystem service categories there is a large range of values, reflective of the many ways people pay for the work of the environment (Campbell 2018). While this could be 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 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, and often the spatial aspect is either not considered or is considered in a limited way. Consequently, the arrived upon value will likely either over or under-estimate 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 resources are available for a study to be done on the particular decision for that specific area.

5. Conclusions

It is becoming increasingly clear that it is necessary to consider the economic value of ecosystem services in our decision making to ensure a sustainable and resilient future. The spatial trend in how ecosystem services change over space, both in biophysical supply and economic demand has implications for how we conserve, restore, and regulate natural lands. These implications are likely transferable, or at minimum will inform, results found in other geographic regions. To our knowledge the information we present here is unique among US states in that we present both biophysical and economic valuation estimates mapped at a 30 m resolution for the entire state. The commitment to utilize the information by the state government is also unique and represents an important step forward for utilizing ecosystem service information for decision making in a formalized way. 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 demonstrates ways these values can be incorporated into the decision-making processes.

- When considering the value provided on a per capita basis, every citizen of Maryland benefits by $1,333 of non-market ecosystem service value every year, or $111 per month..

- 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 current population 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.

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