The Economic Value of the Ecosystem Services of the Chesapeake Bay

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A Thesis presented to the Graduate Faculty
of the University of Virginia in Candidacy for
the Degree of Master of Arts

Department of Environmental Sciences

University of Virginia
August, 2005

Abstract

The Chesapeake Bay has been exploited by humans even before the first Europeans arrived in the area. Today, the pattern continues and despite governmental interference, the Bay is being severely exploited. In spite of all the harmful practices that humans have performed on the estuary, it still provides a vast number of ecosystem services. These ecosystem services are extremely important to not only the people who live in the area, but people across the globe as well, since it plays a vital part in the global nutrient cycle. These services, however, lie outside the realm of conventional markets and are thus, under-valued. It is this under-valuation of ecosystem services that is the root of the environmental degradation experienced today. This paper uses data previously collected on the willingness-to-pay for specific ecosystem services, to calculate the economic value of the Chesapeake Bay ecosystem services. If the public and policy makers were made aware of these values and applied them effectively through a cost-benefit analysis or multi-criteria decision analysis, then many more socially efficient decisions regarding the environment would be reached.

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Introduction

The Chesapeake Bay is one of the largest, most productive and most complex estuaries in the world and is the largest in the United States. The Bay's watershed covers over 166,000 km^2 and includes parts of New York, Pennsylvania, West Virginia, Delaware, Maryland, Virginia, and all of the District of Columbia. It provides a vital habitat to a vast number of different plants and animals. The Bay area has been inhabited for the last 10,000 years and its high productivity has made it an attractive place for human settlement (Ray and McCormick-Ray, 2004).

European settlers arrived to the Chesapeake Bay area in 1607, when it was home to roughly 45,000 Native Americans. At this time, forests covered close to 95% of the watershed and the estuary teemed with life (Kraft and Brush, 1981; as quoted from United States Department of Agriculture (USDA), 1996). European settlers quickly saw the high productive value of the land and immediately began to exploit it for its consumptive uses. Lumber was one of the first exports of the area and became vital to its early success as a center of ship masts and timber (USDA, 1996). Forests were also cleared for agriculture (mainly tobacco), fuel, and space for the growing population. By the mid-1800s, approximately 40-50% of forest area was reduced (Ray and McCormick-Ray, 2004). With the diminishment of soil stability that trees provided, the rivers and streams of the watershed began to fill up with massive amounts of sediment that eroded from the unprotected farmlands and many of the waterways also became obstructed by damns. To make matters worse, many fisheries were being overexploited as well.

During the beginning of the century, laws were passed protecting forests, which allowed them to rebound slightly. However, this caused ever-expanding agriculture to drain wetlands, which were at the time considered wastelands that had no useful function (USDA, 1996).

As the century wore on, so did the degradation of the Chesapeake Bay. Wetlands were continually cleared, fisheries continually overexploited (the Oyster and Shad fisheries were almost wiped out), and the shorebirds and waterfowl populations were decimated through hunting and habitat loss (Ray and McCormick-Ray, 2004). The area of submerged aquatic vegetation (SAV), or seagrass, was also drastically reduced, primarily from eutrophication and sedimentation making the water too turbid (Environmental Protection Agency (EPA), 2000; United States Geological Survey (USGS), 2002). Today population growth, urban sprawl, exotic species, nutrient enrichment, and sediment loads are the most serious threats the Chesapeake Bay faces. It is estimated that 100 acres of forest is lost everyday within the Chesapeake Bay watershed (Chesapeake Bay Program (CBP), 1997). The problems have become so bad that in 1999, the bay was listed as an "impaired water body" (USGS, 2002).

The historic and incessant decline of the environmental health of the Chesapeake Bay can essentially be attributed to the under-valuation of the ecosystems within the Chesapeake Bay and the services they provide, which, in turn, has interfered with any and all attempts towards governmental control and management. The first European settlers saw the value of the environment only for what they could directly consume (i.e. fish, timber, land for agriculture, etc.). They felt that the land had to be "tamed and improved-and ultimately made to turn a profit" (USDA, 1996, page 4). However, little did they realize that by "taming" the ecosystem services they relied upon, they were in fact undercutting their economic viability. This trend has more or less continued on until today, and as natural ecosystems become scarcer, their values increase.

There have been many attempts by certain governments and organizations to curtail the environmental degradation the Chesapeake faces today. The Chesapeake Bay Riparian Forest Buffer Initiative was started in 1996 and has had some success in replanting some forest zone buffers. However, many more miles of these zones still need to be replanted or restored. The newest attempt has been the *Chesapeake 2000.* Results, however, have been nominal at best. In 2004, the model used to calculate nutrient reduction goals was found to be overestimating pollution reductions realized by state efforts (CBP, 2004). Governmental attempts to protect and restore the quality of the Chesapeake Bay environment will not be fully viable until the proper, much higher, economic value of the ecosystem services that it provides is realized and incorporated into management strategies within a landscape perspective.

A landscape perspective would entail the integration of the biological and physical interactions "among a mosaic of ecosystems in heterogeneous land areas that together comprise landscapes" (Soderqvist *et al.* 2000, page 1). At the same time, policy makers must realize that the economic evaluation of ecosystem services still has many limitations, both ethically and technically, that must be dealt with appropriately. Therefore, the economic value of ecosystem services should be an important factor for policy makers, but should not be the sole criterion.

Ecosystem Services

Before trying to evaluate the ecosystem services that the Chesapeake Bay provides, the definition of ecosystem services must first be delineated. Daily describes ecosystem services as "the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life" (1997, page 3). Essentially, ecosystem services are the goods, such as timber, seafood, biomass fuel etc.; and the life-support functions, such as the removal, recycling, and renewal of nutrients and harmful substances; that maintain biodiversity and the production of ecosystem goods (Daily, 1997; Costanza *et al.* 1997). Humans are utterly dependent on ecosystem services to sustain life, and within the Chesapeake Bay region this is no exception.

The Chesapeake Bay Ecosystem Services

The Chesapeake Bay watershed contains a variety of different types of ecosystems and for the purpose of this paper shall be broken up into: estuary, seagrass, temperate forest, lakes and rivers, tidal marsh (estuarine wetlands), swamps and floodplains (palustrine wetlands), and agriculture (Costanza *et al.* 1997). Both among and within each ecosystem, there are a variety of different services that are performed and a summary of these services are listed in Table 1.

Estuary and Seagrass Beds

Estuaries and seagrass beds are both extremely productive ecosystems and are highly interconnected. They provide disturbance regulation, nutrient cycling, biological control, habitat, food production, raw materials, recreation, and cultural services (Costanza *et al.* 1997). The most important of these, in both an ecological and economic point of view, are nutrient cycling, disturbance regulation, food production, and recreation (Table 2).

In this paper, only nitrogen and phosphorus cycling is considered since they are the major macronutrients that are currently affecting the Chesapeake Bay, even though estuaries and seagrass beds, as well as wetlands, do play a vital role in the cycling of other nutrients, such as sulfur, potassium, and silica. Once molecular nitrogen gas is converted to a reactive form, through nitrogen fixation, the only way that it can be returned to the atmosphere is through denitrification, an anaerobic process accomplished by denitrifying bacteria (Galloway *et al.* 1996). Estuaries and seagrass beds have been identified as some of the major ecosystems in which a significant amount of denitrification occurs. Denitrifying bacteria remove excess nitrogen that has flowed into the estuary, or seagrass bed, and releases the nitrogen back into the atmosphere as an inert gas. Phosphorus, on the other hand, does not have a pathway for removal to the atmosphere; the only way it can be removed from the water is by absorption into biomass, a short term reservoir, or by accumulating in sediments and deposition with iron and aluminum (Galloway *et al.* 1996; Daily, 1997). Since the oceans and coastal waters are serving as sinks to all of the world's water that flows from rivers, these marine waters provide a nutrient cycling service, and the estuaries have been estimated to provide approximately one third of this service (Nixon *et al.* 1996).

Estuaries and seagrass beds also play an important role in disturbance regulation, mostly through the dissipation of wave energy during storms, which protects natural systems, but more importantly, from an economic point of view, protects urban areas. Estuaries and seagrass beds accomplish this by the organisms that grow along the bottom with the roots and blades of vegetation effectively causing friction within the water column and dissipating the wave energy, while stabilizing the sediment (EPA, 2000; Ray and McCormick-Ray, 2004).

The Chesapeake Bay is still a productive fishery, despite the drastic declines in certain industries. The Bay still provides 500 million pounds of seafood per year and 70-90% of the striped bass in the Atlantic Ocean use the Bay as a spawning ground. The Bay is also extensively used for recreational purposes, such as sport fishing, hunting, and bird watching. The number of anglers that took fishing trips in Maryland and Virginia in 1998 was close to 1.4 million (EPA, 2000).

Wetlands

Wetlands, both tidal marshes and swamps/floodplains (includes riparian wetlands), are highly dynamic and productive systems. Wetland services include water regulation, water supply, gas regulation, waste treatment, biological control, habitat, food production, raw materials, recreation, cultural, disturbance regulation, erosion control, nutrient cycling, and soil formation. No economic values have been assigned to these last two services because there is a lack of studies dealing explicitly with them, although they are very often incorporated in other values (Costanza *et al.* 1997, Zedler, 2003). However, Baltimore Harbor alone spends $10 to11.5 million every year to dredge the deposited sediments from the harbor floor to keep it navigable (CBP, 1997a). Possibly the most important of these values within the Chesapeake Bay are flood-control, storm protection, nutrient cycling, and waste treatment.

Wetlands have a vegetative structure that allows them to have a large capacity to temporarily hold water. At the same time, floodplains will slow the flow of floodwater downstream. These characteristics allow wetlands to greatly mediate floods and delay both the peak flooding times and the drying phase. In 1993, the Mississippi River Valley experienced massive flooding causing massive property damage estimated at $12 billion (Myers and White, 1993; quoted in Daily, 1997). Prior to the flooding, the Mississippi River Valley had experienced drastic amounts of wetland area reduction. In the Upper Midwestern region, 60% of the historic wetland area of the region has been lost to agriculture (Zedler, 2003). It has been estimated that a relatively small area of retained wetland could have alleviated a great deal of the flooding during 1993, thus saving billions of dollars in damages (Daily *et al.* 1997). This same phenomenon was seen in Virginia between 1994 and 1995 when severe flooding created major damage across the state totaling over $10 million. Areas that had riparian forests and active floodplains had significantly less damage than those areas that did not. Fairfax County has reduced storm water costs by $57 million through the retention of forest areas (CBP, 1998).

Related to this, and similar to the storm protection provided by estuaries and seagrass beds, wetlands provide protection against storms. Wetlands create surface friction for tidal surges and waves, and also reduce the heat source of energy for the storm (Costanza *et al.* 1989). The marsh grass *Spartina alterniflora*, a common plant found in the intidal marshes of the Chesapeake Bay, can dissipate 50% of the wave energy within the first 2.5m of marsh (Ray and McCormick-Ray, 2004).

Wetlands have the capability to capture and cleanse large amounts of nutrients and pollutants without harming their own natural functions (Costanza *et al.* 1997). The removal of nitrogen and phosphorus has already been discussed and the processes are similar for wetland ecosystems. Wetlands have the ability to remove an average of 75% of nitrogen inputs, which can be continued indefinitely; however, there is a limit to how much phosphorus can be removed from the water by the wetland (Daily, 1997; Zedler, 2003).

Forests

Forests supply a lot of direct use values to humans, such as timber and food. Their presence can also boost real estate values. Some have thought of forests as a financial cost when it comes to real estate values due to the loss of open and developable space. This, however, does not seem to be the case. In Maryland, developer premiums are 10-15% higher for lots adjacent to forests. In California, home prices have increased on average 17% due to the presence of trees and buffer zones (CBP, 1997a). However, it is the values that do not fully show up in the marketplace that procure the greatest value.

Forests are key to climate regulation, waste treatment, and erosion control (there were no specific estimates for temperate forests for this value, so no value has been given to this service for this paper).

Forests are valuable waste removers within a watershed. Forests typically retain 70 to 80% of atmospherically deposited nitrogen, thus the lost of forests will lead to more nitrogen entering the bay (USDA, 1996). Forests are also important in stabilizing soils. Without such services, not only will the sediment load in the Chesapeake Bay increase drastically but also fertile soil will be lost forever.

Perhaps the largest contribution to human welfare of forests is the regulatory role that they play in both the global and local climate. Forested areas within cities have the ability to save 4% on heating costs and an additional 10% of cooling expenses (USDA, 1996). Forests, through photosynthesis, are vital to the attempts to diminish the impacts of global warming from fossil fuel production of carbon dioxide. One acre of trees can sequester 40 tons of carbon annually, whereas at the same time releasing 108 tons of O_2 gas. This quantity of oxygen is the amount required to sustain 1,000 people over the course of a year (USDA, 1996; Daily, 1997).

Lakes/rivers

There are more than 100,000 streams and rivers that drain into the Chesapeake Bay. However, there are five major tributaries, the Susquehanna, Potomac, Rappahannock, York, and James that provide almost 90% of the freshwater to the Bay (EPA, 2000; Ray and McCormick-Ray, 2004). Rivers play a critical part in water regulation, water supply, and waste treatment, while at the same time providing food, and numerous recreational activities. They are an important irrigation input for agriculture in the Chesapeake Bay region and are also an important source for residential and industrial water consumptive needs. Without the dilution effect of rivers, pollution controls would have to be even more stringent in reducing nutrient and pollutant loads from cities, farms, and industries (Daily, 1997; Costanza *et al.* 1997).

Rivers have also had a very strong effect on revitalizing urban areas. Both Chicago, Illinois and Hartford, Connecticut have spent a great deal of money restoring the major rivers that go through their downtown districts (the Chicago River and the Connecticut River respectively) in order to promote redevelopment and the quality of life within the city. Both projects have been a success, revitalizing the properties around the river and creating a larger tax base. It has even been suggested that the increase in quality of life from restoring the rivers has led to large corporations relocating to their cities (e.g. Boeing's relocation of its corporate headquarters in 2001 to the South Branch of the Chicago River) (Otto *et al.* 2004). The increase in recreation and aesthetic values of the rivers and their surrounding riparian wetlands are believed to be the catalysts for the increase in property values in the major cities, something large cities within the Chesapeake Bay watershed need to consider, especially Washington D.C. and Richmond, VA.

Cropland

Cropland, or agriculture, primarily provides food and has been a mainstay in the Chesapeake Bay economy since European settlers first arrived. Unfortunately, however, the need for more cropland has also been one of the main excuses given for the clearing of the Bay's forests. Despite this, agriculture is vital to fulfill the food demands of an ever growing population and will continue to do so in the coming future. Cropland also provides pollination services and biological services.

It is evident that all of these ecosystems provide various services and many of them are related and dependent on each other. It should be noted, however, that for each one of these ecosystems (except for agriculture), the services that have the significant number of the highest values are services that barely, if at all, show up in the market place (Table 2). For example, the largest ecosystem service value for both estuaries and seagrass beds, by a significant amount, is nutrient cycling, which is not a tradable commodity and is also one that is very hard on which to place a monetary quantity. Another point that should also be mentioned is that within each ecosystem, not every part will function the same. Thus, the ecosystem services provided, as well as the quantity and quality, vary within an ecosystem. This next section will address this point with a focus on the hydrogeomorphic principles.

Ecosystem Service Variability Within an Ecosystem

The function of a particular forest or wetland will depend on many characteristics, which, in turn, will affect the quality and quantity of the ecosystem services it provides and their subsequent value. The location, size, and connectivity are three very important characteristics that will affect the services of an ecosystem and its values. Location is important for many aspects. How close a forest is to a river will affect its relative importance for nitrogen removal for that particular stream. The location of a forest relative to humans will be an important determinant for the recreational value of the forest. A remote forest that is hard to access will have a much smaller recreational value than an easily accessible forest near an urban area. A policy maker must take into account these spatial differences and must look at the entire landscape in order to properly value an ecosystem and to make a rational decision regarding it. Specific examples with regard to wetlands are used in the next section to further elaborate this point.

The Hydrogeomorphic Principles

The function of wetlands depends on not only the type but also the hydrogeomorphic position within the landscape. The hydrogeomorphic position is defined by Mitsch and Gosselink as the "degree to which a wetland is open to hydrologic and biological fluxes with other systems, including urban and agricultural landscapes" (2000, page 29). Essentially, each wetland is ecologically unique and its functional characteristics depend on its size and where it is situated within the landscape. A wetland that lies along, or is downstream from, a river, will have many different functions, as well as a different level of quality for these functions, than a wetland that is isolated from, or upstream of, the river. Similarly, a wetland that is connected to many other wetlands, creating a network of wetlands, will have different ecosystem services, again at a different level of quality, than another wetland that is isolated by itself. To better illustrate this point, a case study of mangroves, although not found in the Chesapeake Bay, is used.

Ecosystem services of Mangroves

Ewel *et al.* (1998) categorizes mangroves into three different hydrogeomorphic types: fringe mangroves, riverine mangroves, and basin mangroves. Fringe mangroves are tide-dominated, and thus receive the brunt of the tides and have salinity close to, or that of, the coastal waters surrounding it. Prop roots, buttresses, and pneumatophores characterize fringe mangroves. Riverine mangroves are river dominated and are flooded by the tides as well as the river, thus they have a moderate salinity. Riverine mangroves tend to be the most productive because they have the highest water turnover. A higher water turnover leads to an increased supply of nutrients, less accumulation of toxic substances in pore waters, and a greater aeration of the soil, all of which are important characteristics for high productivity. Basin mangroves exist behind fringe and riverine mangroves and usually cover large areas. Owing to their location behind both of the other types of mangroves, tides rarely inundate them. Soil salinity, however, is not always low. If there is a high rate of evapotranspiration, salts will accrue, creating a very saline environment. It is understood that there is no distinct boundary between these three hydrogeomorphic types of mangroves, but making such generalizations will help to elucidate how ecosystem functions differ due to a difference in hyrdogeomorphic position.

Mangrove forests are effective at trapping and retaining sediments from upland areas. Riverine mangroves, however, are the most effective at trapping and retaining sediments due to the fact that river water carries a higher sediment load than tides do. Basin mangroves and fringe mangroves can accomplish this task as well, but not to the same extent due to their position within the landscape.

Mangrove forests also play an important part in the processing of organic matter and nutrients. Fringe mangroves and riverine mangroves have high productivity and short residence times of litter, thus leading to a high amount of organic matter exported to nearshore water. However, when the area of basin mangroves is much larger than the area of riverine or fringe mangroves, basin mangroves might equal or even exceed the amount of organic matter exported. When it comes to being a nutrient sink (mainly inorganic nitrogen), basin mangroves tend to be the best due to the probability of denitrification in an anaerobic environment.

Mangroves play an important part in the support of many animal populations within the mangroves and offshore, some of which spend only part of their life cycle within the mangroves. Fringe and riverine mangroves tend to support the most animals. This can be accounted for by two reasons. The first, as already discussed above, is that fringe and riverine mangroves are major suppliers of detritus, thus being able to support higher trophic levels. Crabs are one animal that benefits from the high supply of organic matter being exported; feeding on the detritus that fringe and riverine mangroves produce. However, it must be pointed out that most crabs live adjacent to mangroves and not actually in them owing to the high concentrations of tannins within the mangroves, which causes poor food quality (Alongi and Sasekumar, 1992; as quoted from Ewel *et al.* 1998). Shrimp are invertebrates that have been hypothesized to feed upon the food chain that mangroves support. Much more frequent inundation of fringe and riverine mangroves, and the protection from predation that well-developed prop roots provide, supplies a habitat and refuge for various fish in both the juvenile and adult stages of life.

There are many other differences in ecosystem services and quality among the three types of mangroves defined above and these are explored in further detail by Ewel *et al.* (1998). In essence, the differences in ecosystem service quality are all dependent on their hydrogeomorphic location and the vegetation type. Other differences in ecosystem service quality exist between the three mangrove types (Table 4).

Temperate wetlands, in general, perform similar functions to mangroves, just in a temperate climate as opposed to a tropical climate (Costanza *et al.* 1997). A similar classification of wetlands, compared to mangroves, was constructed by Mitsch and Gosselink (2000), but the wetlands were organized into four categories instead of three: in-stream wetland, riparian wetland, isolated basin, and coastal (fringe) wetland (Table 3). Each position in the landscape has an enhancement to the value of the ecosystem. Understanding the differences between the type of wetlands and how their hydrogeomorphic position affects their services is crucial for decision makers in order to determine the best use for wetlands and to determine the implications of any decisions made. The ideas behind the hydrogeomorphic principle must also be used when attempting to evaluate the values of other ecosystems as well.

Why Put an Economic Value on an Ecosystem?

Today, with a population of over 15 million, the environmental health of the Chesapeake Bay is under increasing pressure. Wetlands were historically seen as having little value. Because of this, they were filled or drained for development and now there are less than half of the wetlands that existed during colonial times (EPA, 2000). Fisheries within the Chesapeake have had a similar tribulation. Oyster reefs used to cover 40% of the tidal Bay bottom and were able to filter a volume of water equal to that of the Bay's in three days (significantly improving water quality). Presently, the oyster reefs are for the most part just remnant beds and grounds for artificial planting (Daily, 1997; Ray and McCormick-Ray, 2004). Owing to the increased turbidity of the water in the Bay resulting from increased sediment loads, nutrient loads, and their subsequent algal blooms, seagrasses and the submerged aquatic vegetation, or SAV, have gone from covering 600,000 acres of the Bay bottom to around 10% of that level (USGS, 2002).

Valuation Issue

Some argue that it is unwise or morally wrong to put a value on an ecological system. The intrinsic rights view holds that every animal, and all natural things, have an intrinsic right to exist. Thus, it is impossible to put a value on any living thing, especially if this is an economic value. However, the fact is that societies cannot escape the value issue. Adding moral arguments to valuation and decisions certainly makes the value issue more difficult and less explicit, but there is still no way of getting around valuations when making decisions regarding ecosystems. Costanza *et al.* described the intrinsic nature of valuations within decisions in the journal *Nature* (1997):

> the decisions we make as a society about ecosystems imply valuations. We can choose to make these valuations explicit or not; we can do them with an explicit acknowledgement of the huge uncertainties involved or not; but as long as we are forced to make choices, we are going through the process of valuation (page 255).

This is the goal of the economic valuation of ecosystem services, to make these valuations more explicit and account for the large uncertainties that one encounters trying to predict the effects of interfering with an ecosystem.

The Need to Correct Market Inefficiencies

When discussing the economic value of an ecosystem service, it is important for the meaning of economic value to be transparent. In economics, value is determined by the relationship between the demand and the supply of a good or service. Essentially, it is the "amount of money a person is willing to give up in order to get a thing, or the amount of money required to give up that thing" (Wilson and Carpenter, 1999, page 773). The problem when dealing with ecosystem services is that a major portion of the value that is provided does not stem from a consumptive use value, but instead from a non-use value.

A non-use value can be considered to be either an existence value or an option value. An existence values addresses the fact that people derive utility from simply knowing that an ecosystem, or the health of an ecosystem, is out there, even if they never use or plan to use it (Krutilla, 1967). An option value, on the other hand, considers the premium that people are willing to pay to forego the use or exploitation of an ecosystem now, in order to have the option to use the ecosystem in the future for another purpose (Desvouges *et al.* 1987). When discussing the economic value of an ecosystem, one must combine both the use and non-use values. The problem with this, however, is that many of the values provided by ecosystem services do not fully show up, if at all, in markets, leading to gross inefficiencies. The most valuable ecosystem services that have already been discussed, fall into this category and can be described as public goods.

Public goods face what is known as the tragedy of the commons. These goods are "open access" goods that have a lack of enforceable property rights, giving individuals no economic incentives to preserve or conserve the resource. Thus, individuals will exploit and pollute without any consideration for the future. Additionally, these ecosystem services exert very large positive externalities on society. Thus, the proper value of ecosystem services is outside of the market and is unrealized by most. In other words, the private benefit of ecosystem services is much smaller than the social benefit (Casey, 2004). When policy makers make a decision concerning an ecosystem service and they do not realize the large positive benefits to society that the service provides, they will very often make decisions that are socially and economically inefficient. Costanza *et al.* state:

> Ecosystem services are not fully captured in commercial markets or adequately quantified in terms comparable with economic services and manufactured capital, they are often given too little weight in policy decisions (1997, page 253)

The constant under-valuation of ecosystem services can also be seen as a total information failure (Costanza *et al.* 1997; Turner *et al.* 2000). Policy makers and the majority of the public do not understand the multitude of values and functions that various ecosystems can provide. The information failure is a threat to the Chesapeake Bay and social welfare since the "economic value of ecosystems is connected to their physical, chemical, and biological role in the overall system, whether the public fully recognizes that role or not" (Costanza *et al.* 1989, page 339). Furthermore, the public does not understand the complex interactions and linkages between ecosystems. Thus, the economic valuation of ecosystem services is a tool to aid policy makers in making socially and economically efficient decisions. The real economic value of ecosystem services must be realized and used in a cost-benefit analysis.

Valuation Methods

When measuring the economic value of ecosystem services it is meaningless to ask what the total value of natural stock is to human well-being. If ecosystem services stopped working, human life and our economic output would be severely affected, which suggests that ecosystem services have an infinite value to economic systems (Costanza *et al.* 1997). Therefore, one must look at the marginal value of ecosystem services because this will predict how much human welfare will change based on a change in quality or quantity of ecosystem services.

Willingness-to-Pay

Evaluating the costs of ecosystems presents a tough challenge. Almost all ecosystem services, if not all, do not show up fully in a market. Oysters and timber might have a price in the market place, but this price does not account for the cost of replacing an ecosystem function if it was exploited in an unsustainable way (in the case of oysters, the replacement costs are being paid now, through the cost of restoration efforts and an decrease in water quality) nor does it account for government subsidies that are very often tied into ecosystem services. Many of these subsidies in the end have an adverse environmental impact. This market value method also cannot capture consumer surplus (Hawken *et al.* 1999; Woodward and Wui, 2001). However, there are many different methods to try and evaluate the price of an ecosystem service despite if it is a consumptive or non-consumptive use.

These methods include damage avoidance, replacement costs, contingent valuation, travel cost, net factor income, or hedonic pricing methods. Each of these methods has their various advantages; however, it has been found that the actual method used is not a primary determinant of value (Woodward and Wui, 2001). The methods listed above are either direct or indirect attempts to estimate the willingness-to-pay (WTP). To get a total value, the WTP method will take all of the individuals and their respective values and aggregate them, counting each one with the same weight.

Calculating the Economic Value of the Chesapeake Bay Ecosystem Services

The calculations done in this paper are all based on the average global values that Costanza *et al.* (1997) derived (Table 2). He found the average value (1994 dollars) for each ecosystem service within an ecosystem, and then added up all of the services of that ecosystem to get a total average value per ha per year for each ecosystem. The average values for each ecosystem were then multiplied by the relative area of each ecosystem within the watershed, to get a total flow value for each one. These were then summed to derive the total ecosystem service value for the Chesapeake Bay and its watershed. Area values are all approximated from the year 2000 and are extracted from various sources (EPA, 2000 for Wetlands; CBP, 2000 for Agriculture, Forest, Urban and Rivers; Orth *et al.* 2001 for SAV; Ray and McCormick-Ray, 2004 for Bay).

The area of the estuary was calculated as the approximate surface area of the Bay (6500km^2) minus the area of SAV (Table 2) (Costanza, personal communication, 2004). The total surface area of water between the Bay and the tributaries was assumed to be 18,130 km^2, so the surface area of the tributaries was just the total surface area minus the surface area of the Bay (Table 2). All service values for "Wetland*s*" are the average value for that service between the two types of wetlands.

Results

The total economic value for all of the ecosystem services within the Chesapeake Bay watershed totaled \$39,333 x10^6 yr^{-1} in 1994 dollars. The estuary had the largest input into the economic value of the entire watershed totaling \$14,156x10^6 yr^{-1}, which was followed by the floodplains with $10,378 x$10^6$ yr^{-1} (Table 2). The estuary is responsible for approximately 36% of the total economic value of the watershed per year although it only accounts for roughly 3.5% of the total land area of the watershed.

Implications for Policy Makers

There are many important limitations to the methods described above that policy makers must consider when trying to use these numbers in a cost-benefit analysis. The first is that this estimation was a crude estimate using global averages. In reality, this value is most likely an underestimate of the true economic value of the Bay. To more accurately ascertain the value of the ecosystem services of the Chesapeake Bay, data specific to the Bay must be collected.

The Chesapeake Bay is one of the most productive estuaries in the world. On top of this, there is a dense, affluent population that lives within its watershed. Both of these factors will most likely lead the local economic valuations to be higher within the Bay than the global averages used in this study. The Chesapeake Bay Foundation, along with all other interested parties, must make a concerted effort to try and collect and quantify local ecological and economic data to be used in an economic valuation. Once this data is collected, various models should be constructed to best value the Chesapeake Bay.

Ecological-Economic Models and Geographical Information Systems

An ecological-economic model can be a powerful tool in trying to accurately assess the economic and ecological properties and interrelationship of an ecosystem.

Ecological-economic models try to couple ecosystem ecology with ecosystem economics. An integrated ecological-economic model tries to do this in one of two ways. The first is to merge separate ecological and economic models into one. The other is to use a system of heuristically connected submodels (Turner *et al.* 2000). Both of these methods rely on compromises and simplifications. For example, an economist may have to take elements or theories from ecology or from an ecological model, then transform and simplify them in order to be able to use them as inputs into their own economic model (or visa versa). Essentially, when conducting a system analysis on ecological and economic models there is a need for the trade-off between generality, precision, and realism (Costanza *et al.* 1993).

A key component to ecological-economic models is the spatial characteristics of the ecosystem in question as well as its position in not only the natural landscape, but the socio-economic one as well. It is for this reason that Geographical Information Systems, or GIS, must be used. To date, GIS has been occasionally used to help calculate and visualize the economic value of ecosystem services calculated through the travel cost method (Bateman *et al.* 1996). It has also been incorporated into certain integrated ecological-economic models when valuing wetlands as already described above (Turner *et al.* 2000). The scope, however, must go beyond wetlands and be applied to the entire Chesapeake Bay watershed. In order for this to occur, a large GIS database must be created and connected to local ecological and economic data, the need for which has already been described. Utilizing ecological-economic models that use GIS data to incorporate spatial heterogeneity will help shed light on some of the deficiencies incurred by some of the methods used in this paper, most likely leading to a higher economic valuation. However, policy makers must still realize that this method is still not perfect since many simplifications have to be made, while at the same time the interconnectedness between ecosystems and their services is still not fully understood. This is elaborated upon in a later section.

Issues with Willingness-To-Pay

Willingness-To-Pay is inherently subjective and socially blind. This means that individuals may have little idea on how ecosystems work, or how they provide valuable services. Yet, an individual's valuation will count just as much as an informed ecologist's value when the total value is derived. At first glance this may seem fair, but in fact it is flawed when applied to trying to figure out what is best for a society. In a perfect world with perfect information, ecologists would have the main say in the valuation question of an ecosystem since they tend to know better than anyone how they function. This, however, is still not sufficient since the distribution of the costs and benefits across different parties involved and different generations, will not be addressed by simply aggregating the costs and benefits to an individual. In the end, the social value of an ecosystem service will most likely be larger than the aggregate (Daily, 1997; Turner *et al.* 2000).

Limitations with Economic Valuation and Cost-Benefit Analysis

Cost-benefit analysis in regards to ecosystems is vitally important. It allows policy makers and the public to place the benefits received from protecting ecosystems on a comparable level to the returns from another development option. The analysis must concentrate the effect of the decision on the ability of the ecosystem to provide its goods and services. However, as previously alluded to, the effect of a policy on the ability of an ecosystem to provide its goods and services requires a substantial amount of local knowledge on that ecosystem's functioning. This knowledge is often imperfect and beyond the scope of present ecological knowledge (Turner *et al.* 2000). In particular, the degradation limit that an ecosystem can withstand before its goods and services stop functioning forever is difficult to know. How would one relate this to an economic value?

The law of scarcity states that as a commodity becomes less abundant, it becomes more valuable. This is true for ecosystem services, but only to the irreversibility point. Once a certain threshold or infrastructure value is reached the ecosystem will begin to degrade and stop functioning completely. This is why when attempting an ecosystem service valuation, the best sustainable use level available must be assumed and a certain infrastructure value must be incorporated into the value, which if surpassed, may be lost forever (Mistch and Gosselink, 2000). The study by Costanza *et al.* (1997) did not incorporate this value, which is one reason that the value derived in this paper is probably an underestimate of the true economic value of the Chesapeake Bay

Policy makers must also realize that there are many moral reasons to protect the environment as well as economic ones. They must appreciate that the economic value is not the sole, nor the primary reason that an ecosystem should be conserved (Daily, 1997). It must also be warned that by assigning values to an ecosystem, some ecosystems may be argued to replace less valuable ones. This is currently done with wetland mitigation, however, there are many controversies to as whether artificial wetlands provide the same services at the same quality level than natural ones do. This can be avoided though by taking a landscape view when evaluating ecosystem services (Mistch and Gosselink, 2000).

The most important concept that this study, and most economic evaluations to date, has left out, or incompletely accounted for, is the interconnectivity between and within ecosystems. Ecosystems are extremely dynamic and complex. No one truly knows how the global ecosystem works and how one small change at a point will affect something, say for example, down river of the initial change. The total flow value for the Bay was an aggregate of the individual values for each service; however, most, if not all, of these services are somehow connected to each other. Thus, effecting one part of an ecosystem can have drastic effects on another part. By evaluating each individual service separately, the link between them is overlooked, which leads to an under-valuation of the ecosystem as a whole. To address this issue, more research must be done and more complex and dynamic ecological-economic models must be developed (Costanza *et al.* 1997).

Multi-Criteria Decision Analysis

A more comprehensive analysis tool that addresses some of the issues with the cost-benefit analysis listed above is multi-criteria decision analysis (MCDA). Multi-criteria decision analysis includes an assortment of criteria, such as "economic efficiency, equity within and between generations, environmental quality, and various interpretations of sustainability" (Turner *et al.* 2000, page 15). The different criteria it incorporates can be weighted in order of what is important to the Chesapeake Bay, which will demonstrate the various tradeoffs a certain policy will entail.

Adding sustainability into the decision process may be the biggest advantage of using MCDA over cost-benefit analysis. Incorporating sustainability will stem the tide of market-orientated interests, while instilling a safe guard and/or minimum threshold towards the uncertainty related to ecosystem services and their values. Sustainability requires that the management of a resource should not inflict excessive costs and the loss of options on future generations (Cumberland, 1991). This will inherently place a greater emphasis on the future state of the Chesapeake Bay, making our decisions more equitable and transparent to future generations, whose inclinations also happen to be a great unknown.

Perhaps the biggest advantage that sustainability adds to the analysis process is that it will place a greater emphasis on preserving ecosystems as a whole instead of their individual components. This will take away special interests of particular people or groups, such as the timber industry. The change in emphasis will also effectively change the focus to the landscape perspective; reducing concerns about the uncertainty surround ecosystem interconnectivity.

Although MCDA uses both ecological and economic data in what one may say is the most socially efficient manner, it can still be overlooked by many policy makers due to its focus on long-term ecological goals. These goals can very often be eclipsed by the short political visions of most policy makers, who are easily persuaded by short-term commercial interests and financial gain (Turner *et al.* 2000). This is why cost-benefit analysis must also be used in conjunction with MCDA. Cost-benefit analysis, if done in a robust and thorough manner, produces compelling, pragmatic, and tangible results, something a policy maker can turn to when his or her decisions are being scrutinized.

Considerations for the Future

Policy makers must embrace the valuation of ecosystems to help them make decisions, but at the same time they must heed all the limitations and implications of valuing an ecosystem service and using a cost-benefit analysis. Policy makers must pay special attention to the scale of time. The function of an ecosystem most likely must be viewed on a long time scale, and thus has the ability to keep providing benefits, while human developments will most likely not even last the duration of a human generation. Using cost-benefit analysis, if done properly, will lead to an economically efficient outcome. However, this does not necessarily lead to the best social outcome. It is the job of policy makers to choose the best social outcome based on the best information they have, and the economic valuation of ecosystem services is an attempt to produce this.

Multi-criteria decision analysis will help lead to this socially efficient outcome. However, it may not be taken seriously by certain policy makers due to the short-term political cycle and the allure of padding the economic "development" of his or her community during their term in office. A parallel use of cost-benefit analysis and MCDA is the most powerful approach to finding the ideal outcome for the Chesapeake Bay, producing the pragmatic data and valuations needed to persuade policy makers and the public.

Conclusion

The economic value of the ecosystem services that the Chesapeake Bay provides is certainly substantial. The value calculated in this study, however, is just a crude estimate based on global averages and is most likely an under-valuation for numerous reasons. Much more local data must be collected in the most comprehensive manner possible, in order to accurately determine the economic value of ecosystem services within the Chesapeake Bay's watershed. Once a value is derived, policy makers must use this value to educate the public and to make the best socially optimal decisions possible. Policy makers, however, must realize the limitations to valuating ecosystem services and understand that there is a great amount of uncertainty involved with it. Thus, precaution must be taken. When an analysis is complete and development slightly outweighs conservation, the side of conservation should be favored over development.

Table 1: Ecosystem Services and functions (based on Costanza *et al.* 1997)		
Ecosystem Service	**Ecosystem Functions**	**Examples in Wetlands**
Gas Regulation	Regulation of atmospheric chemical composition	CO_2/O_2 balance and SO_X levels
Climate Regulation	Regulation of global temperature, precipitation, and other biologically mediated climatic processes at global or local levels	Greenhouse gas regulation, DMS production affecting cloud formation
Disturbance Regulation	Capacitance, damping and integrity of ecosystem response to environmental fluctuations	Storm protection, flood control, drought recovery and other aspects of habitat response to environmental variability
Water Regulation	Regulation of hydrological flows	Provisioning of water for agricultural or industrial processes or transportation
Water Supply	Storage and retention of water	Provisioning of water by storage in wetlands
Erosion control and sediment retention	Retention of soil within an ecosystem	Prevention of loss of soil by wind, runoff, or other removal processes, storage of silt in lakes and wetlands
Soil Formation	Soil Formation processes	Weathering of rock and the accumulation of organic material
Nutrient Cycling	Storage, internal cycling, processing and acquisition of nutrients	Nitrogen fixation, N, P and other elemental or nutrient cycles
Waste Treatment	Recovery of mobile nutrients and removal or breakdown of excess or xenic nutrients and compounds	Waste treatment, pollution control, detoxification
Pollination	Movement of floral gametes	Provisioning of pollinators for the reproduction of plant populations
Biological Control	Trophic-dynamic regulations of populations	Keystone predator control of prey species, reduction of herbivory by top predators
Habitat/Refugia	Habitat for resident and transient populations	Nurseries, habitat for migratory species, regional habitats for locally harvested species, or overwintering grounds
Food Production	That portion of gross primary production extractable as food	Production of fish and game by fishing and hunting
Raw Materials	That portion of gross primary production extractable as raw materials	The production of lumber, fuel, or fodder
Recreation	Providing opportunities for recreational activities	Eco-tourism, sport fishing, bird watching, and other outdoor recreational activities
Cultural	Providing opportunities for non-commercial uses	Aesthetic, artistic, educational, spiritual, and/or scientific values of ecosystems

Table 2: Summary of average Chesapeake Bay value of annual ecosystem services (adapted from Costanza *et al.* 1997)

Ecosystem	AR	GR	CR	DR	WR	WS	SF	NC	WT	PO	BC	HR	FP	RM	RC	CL	TV	Total
Estuary	62			567				21,100			78	131	521	25	381	29	22,832	**14,156**
Seagrass & SAV	3							19,002						2			19,004	**570**
Temperate Forest	1,034		88		0		10		87		4		50	25	36	2	302	**3,123**
Tidal Marsh	8			1,839					6,696			169	466	162	658		9,990	**799**
Swamps/ Floodplains	53	265		7,240	30	7,600			1,659			439	47	49	491	1,761	19,580	**10,378**
Lakes/ Rivers	116				5,445	2,117			665				41		230		8,498	**9,858**
Cropland	489									14	24		54				92	**450**
Urban	62																	
Total	**1827**	**141**	**910**	**4,336**	**6,332**	**6,484**	**103**	**13,656**	**3086**	**69**	**207**	**327**	**1,214**	**313**	**1,188**	**972**		**39,333**

Numbers in the body of the table are in **$ ha^{-1} yr^{-1}**. Row and column totals are in **$ yr^{-1} x 10^{6}**. Column totals are the sum of the products of the per ha services in the table and the area of each ecosystem, not the sum of the per ha services themselves. Row totals are the sum of the products of the per ha service for each ecosystem and the area of each ecosystem. Shaded cells indicate services that do not occur or are known to be negligible. Open cells indicate a lack of available information. Both erosion control and genetic resources were left out of the table due to the lack of information regarding their services within the ecosystems that are a part of the Chesapeake Bay.

AR- Area (**ha x 10^{4}**); GR- Gas Regulation; CR- Climate Regulation; DR- Disturbance Regulation; WR- Water Regulation; WS- Water Supply; SF- Soil Formation; NC- Nutrient Cycling; WT- Water Treatment; PO- Pollination; BC- Biological Control; HR- Habitat/Refugia; FP- Food Production; RM- Raw Materials; RC- Recreation; CL- Cultural; TV- Total Value per ha; Total- Total Flow Value (**$ y^{-1} x 10^{6}**).

Table 3: Examples of wetland position in the landscape and related probable values (based on Mitsch and Gosselink, 2000)

Position in landscape	Enhanced Value
In-stream wetland	Fisheries, organic export
Riparian wetland	Detrital production; sediment retention; wildlife corridor; flood control; nitrogen and phosphorus retention; migratory song-birds
Isolated basin	Groundwater recharge; flood control; waterfowl; amphibians
Coastal (fringe) wetland	Fisheries; offshore productivity; waterfowl; storm buffer

Table 4: Relative importance of different types of mangrove forests in providing goods and services. 1= most important (based on Ewel *et al.* 1998)

Role	Riverine	Basin	Fringe
Trap sediments	1	2	3
Process nutrients and organic matter			
Provide a source of detritus to nearshore waters	1	3	2
Serve as a sink for nutrients and carbon			
C, N	2	1	3
P	1	3	2
Improve water quality	2	1	3
Provide food and habitat for animals	1	3	2
Provide aesthetically pleasing environments	1	3	2
Protect shorelines	2	3	1
Provide plant products	2	1	3

References:

Alongi, D.M., Sasekumar, A. 1992. Benthic communities. Tropical mangrove ecosystems: coastal and estuarine studies 41, 137-171.

Bateman, I.J., Garrod, G.D., Brainard, J.S. and Lovett, A.A. 1996. Measurement, valuation and estimation issues in the travel cost method: a geographical information systems approach. Journal of Agricultural Economics, 47, 191-205.

Casey, J.F., 2004. The Value of Riparian Forest Buffers in the Chesapeake Bay Watershed: An Economic Framework for Policy-making. *Economics and the Chesapeake Bay Workbook Series*. National Oceanic and Atmospheric Administration. http://home.wlu.edu/~caseyj/noaa.htm

Chesapeake Bay Program, 2004. *Report Finds Bay Restoration in Peril.* http://www.cbf.org/site/News2?page=NewsArticle&id=9636

Chesapeake Bay Program, 2000. www.chesapeakebay.net

Chesapeake Bay Program, 1998. *Economic Benefits of Riparian Forest Buffers*. Ref 600.613.1 Fact Sheet.

Chesapeake Bay Program, 1997. *Riparian Forest Buffers in the Chesapeake Bay Watershed.* Fact Sheet. http://www.chesapeakebay.net/pubs/subcommittee/nsc/nsc610.pdf

Chesapeake Bay Program, 1997a. *Chesapeake Bay Riparian Handbook: A Guide for Establishing and Maintaining Riparian Forest Buffers.* http://www.chesapeakebay.net/pubs/subcommittee/nsc/forest/handbook.htm

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., *et al.* 1997. The value of the world's ecosystem services and natural capital. Nature 387, 253-260.

Costanza, R., Wainger, L., Folke, C., Maler, K.G. 1993. Modeling complex ecological economic systems. Bioscience 43, 545-555.

Costanza, R., Farber, C.S., Maxwell, J. 1989. Valuation and management of wetland ecosystems. Ecol. Econ. 1, 335-361.

Cumberland, J.H. 1991. Intergenerational transfers and ecological sustainability. In: Costanza, R. *Ecological Economics: The Science and Management of Sustainability*, Columbia University Press, New York.

Daily, G. 1997. *Nature's Services: Societal Dependence on Natural Ecosystems*, Island Press, Washington D.C.

Desvouges, W.H., Smith, V.K., Fisher, A. 1987. Option price estimates for water quality improvements: a contingent valuation study for the Monongahela River. Journal of Environmental Economics and Management 14, 248-267.

Environmental Protection Agency, 2000. Chesapeake Bay submerged aquatic vegetation eater quality and habitat-based requirements and restoration targets: a second technical synthesis.

Ewel, K.C., Twilley, R.R., Ong, J.E. 1998. Different kinds of mangrove forests provide different goods and services. Global Ecology and Biogeography Letters, 7, 83-94.

Galloway, J.N., Howarth, R.W., Michaels, A.F., Nixon, S.W., Prospero, J.M., Dentener, F.J. 1996. Nitrogen and phosphorus budgets of the North Atlantic Ocean and its watershed. Biogeochemistry 35, 3-25.

Hawken, P., Lovins, A., Lovins, L.H. 1999. *Natural Capitalism*, Little, Brown, and Company, USA.

Kraft, J.C. and Brush, G.S. 1981. *A Geological-Paleoenvironemental Analysis of the Sediments in St. Johns Pond and the Nearshore Zone near Howard's Wharf at St. Mary's Cit, Maryland*. Unpublished manuscript, Baltimore, MD.

Krutilla, J.V. 1967. Conservation reconsidered. American Economic Review 57, 777-786.

Mitsch, W.J., Gosselink, J.G. 2000. The value of wetlands: importance of scale and landscape setting. Ecol. Econ. 35, 25-33.

Nixon, S.W., Ammerman, J.W., Atkinson, L.P., Berounsky, V.M., Billen, G., Boicourt, W.C., Boynton, W.R., Church, T.M., Ditoro, D.M., Elmgren, R., Garber, J.H., Giblin, A.E., Jahnke, R.A., Owens, N.J.P., Pilson, M.E.Q., Seitzinger, S.P. 1996. The fate of nitrogen and phosphorus at the land-sea margin of the North Atlantic Ocean 35, 141-180.

Orth, R.J., Wilcox, D.J., Nagey, L.S., Whiting, J.R. Fishman, J.R. 2001. 2000 Distribution of submerged aquatic vegetation in Chesapeake Bay and coastal bays. Virginia Institute of Marine Science, Gloucester Point, VA http://www.vims.edu/bio/sav/sav00/

Otto, B., McCormick, M., and Leccese, M. 2004. *Ecological Riverfront Design: Restoring Rivers, Connecting Communities*. American Planning Association, Chicago, Il.

Ray, G.C., McCormick-Ray, J. 2004. *Coastal-Marine Conservation: Science and Policy*, Blackwell Publishing, Malden, MA.

Soderqvist, T., Mitsch, W.J., Turner, R.K. 2000. Valuation of wetlands in a landscape and institutional perspective. Ecol. Econ. 35, 1-6.

Turner, R.K., van den Bergh, J.C.J.M., Soderqvist, T., Barendregt, Straaten, J., Maltby, E., Ierland, E.C. 2000. Ecological-economic analysis of wetlands: scientific integration for management and policy. Ecol. Econ. 35, 7-23.

United States Department of Agriculture. 1996. Conserving the forests of the Chesapeake: the status, trends, and importance of forests for the Bay's sustainable future. http://www.chesapeakebay.net/pubs/127.pdf

United States Geological Survey, 2002. The U.S. Geological Survey and the Chesapeake Bay-the role of science in environmental restoration. Reston, Va.

Wilson, M.A., Carpenter, S.R. 1999. Economic valuation of freshwater ecosystem services in the United States: 1971-1997. Ecological Applications 9, 772-783.

Woodward, R.T., Yong-Suhk, W. 2001. The economic value of wetland services: a meta-analysis. Ecol. Econ. 37, 257-270.

Zedler, J.B. 2003. Wetlands at your service: reducing impacts of agriculture at the watershed scale. Front Ecol Environ, 1, 65-72.