Evaluating the Impacts of Discount Function and Rate Selection on the Net Present Valuation of Coastal Wetland Ecosystem Services: An Exploratory Meta-Analysis

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Abstract

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This thesis explores the impact of discount function and rate selection on the net present valuation of coastal wetland ecosystem services in the context of benefit cost analysis. Using valuation estimates from peer-reviewed literature, the effects of exponential and hyperbolic discounting functions are compared across several discount rates and time horizons. The choice of discount rates, as well as discount functions, appears to have a considerable impact on net present value, especially on a long time horizon. This thesis questions the seemingly arbitrary assignment of high discount rates for benefit cost analyses involving ecosystem services, addressing the underlying economic theory and associated market failures that arise from attempting to value public goods that likely exhibit increasing returns. A close examination of transaction cost economics suggests that the biophysical characteristics of ecosystem services, coupled with incomplete information regarding preferences of future generations and the sheer number of individuals and firms acting as stakeholders, may serve as a barrier to transactions and the establishment of an efficient market to signal the true value of an ecosystem. Uncertainty regarding estimated ecosystem service values and the future impacts of climate change lead to the conclusion that a regulatory framework may provide a more effective means of protecting natural capital.

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Chapter One: Introduction

As a society, we are faced with increasing degradation of our natural environment and future uncertainty with regards to climate change. While many people recognize the intrinsic value of ecosystems and the environment, policy makers and local agencies often struggle with balancing the preservation of ecosystems and the economic gains associated with development during the decision making process. In recent years, researchers have focused on determining the economic value of ecosystem services, often with the hope of creating a systematic and objective method by which the value of these services can be incorporated into benefit cost analysis. Though significant investigation into this topic has already been undertaken, there are still many questions regarding the methodological framework by which these values are calculated. One of the major issues in question is the selection of discount rates: when conducting benefit cost analysis over a given time horizon, a discount value is applied to address depreciation and consumption preferences, allowing values in future years to be adjusted to their respective present values and summed to calculate a net present value. This method is broadly accepted for quantitative analysis of tangible assets over a short time period in which risks and uncertainties can be reasonably assessed.

But what happens when cost-benefit analysis is applied to ecosystem services on long-term time horizons, such as those that should be considered when looking at the lasting impacts of land use decisions? Given the vast uncertainties regarding future conditions or risks, it may be inappropriate to use a simple, constant discount rate to assess values in far-future years (Green, 2012; Kolstad, 2011: 119-122). Uncertainties with regards to ecosystem service valuation manifest through two primary drivers: changing human preferences over time and stochastic environmental changes, including climate change.

Consider the case of continued greenfield development or excessive pollution released into the environment—over time, intact and functional ecosystems will become increasingly scarce, thereby leading to the assumption of increased future values. If future values are dynamic, a static discount rate applied to the current year's value will not appropriately represent changing relative values and preferences. The Intergovernmental Panel on Climate Change (IPCC) has echoed this sentiment of uncertainty through its predictive models of future climate change impacts. Though the IPCC can say with a high degree of certainty that climate change will result in the rise of sea levels globally, the magnitude and timing of this change is variable, depending on greenhouse gas emissions as well as ecological and climate feedback loops (IPCC, 2013). Another important consideration is the inherent uncertainty in calculated valuations of ecosystem services. As non-market goods, ecosystem services are not valued using traditional methods. Instead, values are calculated indirectly, and may not be fully inclusive of all benefits, thus leading to their systematic undervaluing.

The commonly accepted method of exponential discounting creates a problematic situation with regards to the application of ecosystem service valuation in benefit costs analysis. At its core, benefit costs analysis seeks to present an objective method for evaluating policy decisions, ranging from whether or not to implement a particular social welfare program to undertaking an ecological restoration project. However, the inherent uncertainties surrounding ecosystem valuations, changing time preferences, and increased scarcity of ecosystem services in the future limit the effectiveness of this method. Because exponential discounting will eventually lead to present values asymptotically approaching zero, net present valuation of ecosystem services may stagnate at a particular value, suggesting that the ecosystem ceases to generate value at some point in the future. However this is a fundamentally false assumption, as healthy ecosystems will continue to be productive and provide services in perpetuity.

Based on these issues, it would be pertinent to consider the use of discount rate functions that change the applied discount rate over time. Hyperbolic discounting may provide an alternative, maintaining higher future values compared to exponential discounting due to its diminishing discount factor as time increases. Hyperbolic discounting may also present a more appropriate model representing society's inter-temporal and inter-generational time preferences (Green, 2012).

This thesis will explore the underlying economic issues surrounding ecosystem service valuation, the failures of exponential discounting rates to adequately represent future values of services in the context of benefit cost analysis, and the potential of hyperbolic discounting to provide a more appropriate simulation of future values. This will be accomplished by utilizing calculated ecosystem service valuation case studies for coastal wetlands, transforming the value per acre based using both exponential and hyperbolic discount functions, and comparing the outcomes over various time horizons to evaluate potential changes in net present values under difference scenarios. Impacts on policy and land use decisions will be explored, as well as future directions for research to improve the use of economic valuation for ecosystem services, especially in the face of future risk and uncertainty

<u>Chapter Two: Review of Relevant Literature</u>

Ecosystems are complex systems consisting of a multitude of stocks, flows, processes, and interactions among their component parts, which generate a number of services that provide substantial benefits to humans. In order to account for such services in the context of benefit cost analysis, we must first understand the economic nature and issues surrounding ecosystem services, how economic values are assigned to nonmarket goods, and how economists and researchers account for future values when determining the total worth of a particular ecosystem service. This literature review presents an overview of what constitutes ecosystem services, their classification as public goods or common pool resources and resulting economic issues that arise from such classifications, and how they can be assigned an economic value. The underlying principles of benefit cost analysis are presented, including the concept of discounting and the calculation of net present value, as well as current practices in applying ecosystem service valuations to benefit cost analysis and the selection of discount rate decisions for such analyses. Finally, issues surrounding exponential discounting are explored, and an alternative hyperbolic discounting model is presented.

2.1 Definition of Ecosystem Services and Underlying Economic Principles

2.1.1 Definition of Ecosystem Services

Though ecosystem services have been around for millions of years, the concept has only recently been formally defined. While the term "ecosystem services" is actually an umbrella for ecosystem goods, functions, and services, it refers to all aspects of the ecosystem that, either directly or indirectly, have some benefit to humans (Costanza *et al*, 1997: 253). These services include, but are not limited to, climate regulation, soil formation, nutrient cycling, waste treatment, pollination, food production, water supply and regulation, disturbance regulation, erosion control and sediment retention, and raw materials (Costanza *et al* 1997: 254). Specific examples of ecosystem services might be the buffering capacity of coastal mangroves against tidal action and storm surges, the transfer and deposition of nutrients from an eroding upstream geologic feature to a downstream floodplain, or the purification of freshwater sources. Basic ecosystem provisions and consumables, such as fisheries and timber, also fit within this definition.

2.1.2 Why should we care about ecosystem services?

One of the key aspects of Costanza *et al*'s definition for ecosystem services is their relation to human benefits. In generic economic terms, humans receive utility from such services. Beyond simply their intrinsic value, ecosystems provide a support system on which many aspects of human society are dependent. For most of human history, our environment has been capable of absorbing human waste and providing people with necessary environmental goods, like food, clean water, and raw building materials. Technological innovation, coupled with exponential growth in the global human population, has stressed ecosystems, leading to their degradation. In order to assure continued ecosystem function and support of the human population, ecosystem services must be identified, quantified, and applied in a way that integrates social, economic, and ecological perspectives into planning and environmental management (Seppelt, *et al*, 2011: 630). This sentiment is echoed by a number of scholars, noting that:

> "… policy makers and multiple land-users and stakeholders should understand that ecosystem services are becoming increasingly scarce and that it is not possible to manage what was not valued. At the same time, they should recognize that the demand for ecosystem services will rapidly increase as populations and standards of life increase worldwide. So they have no choice; *ecosystem service valuation is the tool to do this*." (Viglizzo *et al*, 2012: 82; emphasis added)

2.1.3 An Ecological Perspective

Ecosystem services are not simply an economic concept—they also stem from an ecological point of view. While the main focus on quantifying these services is to represent the economic benefits received by humans, ecosystem services can be more broadly approached from an ecological management and ecological health perspective, thus emphasizing the function and quality of the services. Naturally, humans are still dependent on ecosystem services, regardless of whether they are valued intrinsically, functionally, or economically. This is especially true when it comes to dealing with degraded landscapes. Rehabilitation of degraded land improves the quality of ecosystem services, ranging from biogeochemical cycles and food production to climate regulation and the provision of habitat to support of biodiversity (Daily, 1995: 350). Even without specific cost values associated with land degradation, it is clearly in the interest of society, and the environment at large, to avoid further damage to these critical ecological services that humans depend on, and often preferable to invest in the restoration of our natural capital (Daily, 1995: 353).

Another ecological consideration with respect to society's view on ecosystem services is the inability to isolate particular aspects of a complex ecosystem and its sub-systems. Unlike microeconomic markets that appear to behave independently of other markets (or at least can be assumed independent to some extent), ecosystems and their related services are difficult to isolate even on a conceptual basis. Therefore, disturbances to one ecosystem service will likely permeate through the complex system, ultimately impacting other services and surrounding ecosystems, which may have implications for the overall resilience of the system as a whole (Ehrlich *et al*, 2012: 69). With respect to environmental management and policy, the inability to distinguish and isolate ecosystems and their services, especially along artificial political and economic boundaries, can lead to inconsistencies in conservation and environmental protection that may compromise efforts on a regional and global scale (Ehrlich *et al*, 2012: 69-71).

2.1.4 Public versus Private Ownership: different types of economic goods

In order to understand why the identification of ecosystem services has become increasingly important, one must first understand the economic nature of ecosystems, specifically why they are not assigned economic value the same way traditional, market goods are valued. Figure 1 summarizes the characteristics of particular types of economics goods and provides examples of such goods.

Figure 1: Summary of Economic Goods, their Characteristic, and Examples (adapted from Daly and Farley, 2011: 169)

	Excludable	Non-excludable
Rival	Market Goods (Private): food, clothes, cars, waste absorption capacity when pollution is regulated	Open Access Regimes (Common Pool Resource, represents the "tragedy of the commons"): fisheries, logging of unprotected forests, air pollution, waste absorption capacity when pollution is unregulated
Non-rival	Potential Market Goods: information, cable TV, technology (if actually a market good, people consume less than they should—marginal benefits remain larger than marginal costs)	Pure Public Goods: national defense, unencumbered radio signals, some ecosystem services (such as storm surge buffering)
Congestible	Toll/Club Goods: ski resorts, toll roads, country clubs (such goods become market goods when scarce, but have zero marginal value when abundant; most efficient when price fluctuates according to usage or if employed to avoid resource scarcity)	Open Access Regimes (Common Pool Resource): non-toll roads, public beaches, national parks (efficiency is increased by making these goods excludable by limiting access during periods of high use)

Excludability and non-excludability, in economic terms, refer to the ability to limit access to a particular good or service. For example, a fee to enter an amusement park makes such an amenity excludable, while an unfenced city park that does not require a fee for entry would be considered non-excludable. Generally speaking, if there is some type of fee (monetary or otherwise) involved in gaining access to a place, a good, or a service, it is considered excludable.[1] The terms rival, non-rival, and congestible refer to whether or not one's individual consumption of a particular good or service has an impact on the ability of others to consume the same good or service (i.e. whether the consumption decisions of one party affect the supply curve of the good or service for others).

2.1.5 Market Failures

Neoclassical economic theory maintains that markets provide for an efficient allocation of goods under ideal conditions. Such conditions include perfect competition, full information, the presence of market (private) goods, the absence of externalities or economies of scale, the assumption of rational actors, no barriers to entry, and no transaction costs, to name a few. When these conditions are violated, the market is not capable of producing an efficient result, ultimately leading to a market failure. Some of the market failures that economists must address when considering the environment are as follows:

[1] It is important to recognize that the presence of mandatory fees is what makes a good excludable. In the case of municipal drinking water, many municipalities have programs that either waive or substantially reduce the associated rates for water provision for low-income individuals, making the municipal water supply non-excludable to a certain extent. The rate paid is also much lower than the actual value of the water.

Public Goods/Open Access Regimes/Club Goods- Lack of excludability prevents an efficient market from forming. Government intervention is often needed to ensure the adequate provision of public goods due to a lack of private incentives to do so (Samuelson, 1954; Buchanan, 1965).

Externalities- Third party impacts are not considered in the decision making process, representing an overall decrease in social welfare that is not being accounted for in given economic decision between non-impacted parties (Pigou, 1932).

Incomplete Information (Information Asymmetry)- Researchers are continually learning more about ecosystems and the environment, as well as how human decisions impact the natural world. It may not be possible to provide full information to all parties or stakeholders involved in the decision making process (Ackerloff, 1970).

Bounded Rationality- When faced with the issue of scarcity or irrefutable facts regarding the degradation of natural resources, rational humans should take steps to avoid unbridled consumption to preserve natural resources. However, many individuals and firms ignore scarcity and degradation, thus leading to the conclusion that rationality is bounded to some extent (Simon, 1972).

Presence of Transaction Costs- Some resources are not perfectly divisible or are limited in some way, leading to the rise of transaction costs. Litigation and regulatory frameworks may also impose transaction costs. Other market failures, including imperfect information and the effort required to involve all parties a particular transaction may in turn give rise to transactions costs (Coase, 1960).

2.1.6 Externalities

One primary driver for the definition of ecosystem services and their subsequent valuation is the desire to address externalities. In economic terms, an externality is a type of market failure in which there is an impact on one party resulting from the decisions of another party (or the interaction of multiple parties) that is not taken into account in the decision making process. Externalities occur when:

> "…one person A, in the course of rendering some service, for which payment is made, to a second person B, incidentally also renders services or disservices to other persons (not producers of like services), of such a sort that payment cannot be extracted from the benefited parties or compensation enforced on behalf of the injured parties." (Pigou, 1932: 183)

A common illustrative example of an externality is pollution. A factory producing widgets generates smoke during its manufacturing process. The smoke subsequently blows over to a neighboring community, causing the deposition of particulate matter, smog, and respiratory illnesses due to poor air quality. If the damages to the neighboring community are not incorporated as a cost in the firm's production function, the pollution generated by production becomes an externality. The firm will continue to operate and chose a production level consistent with the free market, effectively ignoring these negative impacts to the surrounding community. In the absence of legislative intervention, the community will be forced to absorb the cost of these negative impacts, even though these impacts are a direct result of the factory's operation.

Externalities do not necessarily result in negative negative impacts. Depending on the nature of the impact, externalities can actually be positive. For example, the installation of a city park may contribute to an increase in neighboring property values. Although this positive impact on property values was not a consideration in the city's decision to create a public park, the decision resulted in a positive impact for private property owners.

2.1.7 The Tragedy of the Commons

Externalities are not limited to the actions of a single firm, nor are the scopes of their impacts limited solely to humans. The natural environment can be subject to the effects of externalities, especially in the case of unregulated public goods. The exploitation of public resources by private entities acting in their own self interest often results in degradation of the resource in question, especially if private actors do not incorporate the impacts of their cumulative consumption into individual decision making processes. This effect, termed the "tragedy of the commons", popularized by Garrett Hardin, has manifested in a number of ways. Resources that were once assumed to be so abundant and self-replenishing that individual takings would never result in a net loss or degradation of the resource have demonstrated a contrary effect. Hardin describes a scenario of cattle grazing on an open pasture, in which each herdsman is compelled by the free market to add additional cattle to the pasture—unfortunately, the market does not signal the cumulative effect of each herdsman's decision, thus creating an externality that manifests in the form of overgrazing and rapid resource degradation (Hardin, 1968: 1244).

It is important to note that this "tragedy of the commons" can also apply to other issues, including pollution. Often, some type of regulatory framework is necessary to address this:

> "The rational man finds that his share of the cost of the wastes he discharges into the commons is less than the cost of purifying his wastes before releasing them…But the air and waters surrounding it cannot readily be fenced, and so there tragedy of the commons as a cesspool must be prevented by different means, by coercive laws or taxing devices that make it cheaper for the polluter to treat his pollutants than to discharge them untreated." (Hardin, 1969: 1245)

Fortunately, the United States today has regulations in place to coerce polluters to treat their waste before it is emitted into the ecosystem. The Environmental Protection Agency has long enforced the Clean Air and Clean Water Acts. However, not all countries or municipalities have been able to curtail pollution, especially those with rapidly growing economies. As China modernizes, many of its major cities have been plagued by poor air quality due to emissions from coal-fired power plants and other industrial processes.

2.1.8 Responding to Externalities: Pigou and Coase

Since the beginning of the Twentieth Century, economists have sought to address externalities in a way that decreases social cost. Two leading scholars who have examined this issue include Arthur Pigou and Ronald Coase. Though they both studied similar phenomena, each came to different conclusions as to how externalities should be addressed.

Pigou theorized that the market could be used to absorb externalities by creating a tax, or Pigouvian fee, set such that the marginal social costs of the fee were equal to the marginal social benefits received by altering the firm's supply curve (Pigou, 1932). In the case of pollution, this tax effectively assigns an inherent property right to the environment on behalf of the state, such that polluters are subject to a certain degree of liability for each unit of pollution they produce (Daly and Farley, 2011: 430). When the tax or fee is applied, it raises the cost of production for the polluting firm, which absorbs social cost of pollution into its production function. It is important to note that in the case of the Pigouvian fee, the assignment of "rights" matters. If the firm were assigned the right to pollute, a tax or fee structure would become irrelevant for reducing pollution unless there was a transfer mechanism in place in which the government collected a tax or fee from residents for the provision of clean air or water and provided compensation to the firm for its abatement.   Pigouvian taxes or fees are typically applied to perceived open access regimes, or common pool resources (see Section 2.1.3) that are rival but not excludable in nature. Pigouvian fees may not always be efficient in reducing pollution or other externalities, especially if they are less than the cost of abatement or do not accurately reflect the marginal social cost of the externality as it changes over time (Kolstad, 2011:243-246). To some extent, Pigou believed that the market could settle the externality issue given a minimal degree of governmental intervention in the form of establishing and enforcing a tax or fee structure in favor of society's benefit and right to be free of pollution.

An alternative approach for internalizing externalities moves away from taxes or fees as a form of indirect market intervention. Modern economic theory and instruction often refers to the "Coase Theorum" as a way to address externalities: regardless of which party was assigned rights (the firm causing the externality versus the party that was negatively impacted by the externality), an efficient level of production and its subsequent internalization of the social cost of the externality could be achieved provided that the rights could be freely exchanged in a perfectly competitive market with no associated transaction costs (Coase, 1960: 1-8). According to this "theory", the government simply needs to define the initial allocation of property rights and enforce them accordingly, while the market does the rest:

> "It is necessary to know whether the damaging business is liable or not for damage caused since without the establishment of this initial delimitation of rights there can be no market transactions to transfer and recombine them. But the ultimate result (which maximises the value of production) is independent of the legal position if the pricing system is assumed to work without cost." (Coase, 1960: 8)

However, this was not the intended conclusion of Coase's work, merely an introduction to the importance of transaction costs within the market. Coase admits that the assumption of no transaction costs within a market, especially a market that attempts to address externalities or social costs from a private action, is "very unrealistic" (Coase, 1960: 15). In fact, even in the absence of cost associated with a pricing system, market transactions of this nature require a good deal of upfront investment in the form of identifying actors within the market, information gathering and dissemination, and negotiation and contracting, followed by the effort required to enforce the contract, resulting in costs that may be so high that they actually prevent an otherwise beneficial transaction from taking place (Coase, 1960: 15). Coase goes on to note the importance of non-market interventions in order to address externalities and social costs:

> "But the firm is not the only possible answer to this problem. The administrative costs of organizing transactions within the firm may also be high, and particularly so when any diverse activities are brought within the control of a single organisation… An alternative solution is direct Government regulation. Instead of instituting a legal system of rights which can be modified by transactions on the market, the government may impose regulations which state what people must or must not do and which have to be obeyed." (Coase, 1960: 17)

While the above statement seems to suggest that government action may be preferable compared to market transactions with high costs for dealing with externalities and associated social costs, this is not always the case. In some instances, the administration of government programs or regulations also have high costs, and therefore it is crucial that a comparison be made between market transactions and direct government regulation to determine which provides a more efficient social outcome (Coase 1960: 17-18).

2.2 Valuation Methods: Monetization of Ecosystem Services

The concept of ecosystem service valuation is quite simple: monetary values are assigned to ecosystem functions in the hope of representing the true value of a given service, and the values of individual services or functions are summed over the entire ecosystem to represent its net worth. By assigning the ecosystem a monetary value, the impact of externalities can be reduced or eliminated if this value is appropriately taken into consideration during economic decisions.

There are several ways that this can be accomplished, depending on the nature of a given service that is being valued. For services that have an established economic market, the market price may be a good method for valuation in some situations. In the case of environmental goods, including timber, fish, food, and other similar consumables, an economic valuation might be easily accomplished by multiplying the known quantity of the good by its market price. This method may also be appropriate to estimate the value of services that constitute a factor of production for a different market good, so long as some information is known about the percentage of contribution that service has towards the overall value of the market good. However, caution should be exercised when employing this method for a large quantity of a particular good: since market prices are determined at the margin, they do not necessarily reflect the value of the entire stock of a particular good in the ecosystem, and may result in greater uncertainty as the quantity becomes increasingly large (Farber *et al*, 2002: 388). This marginal value issue is exemplified by permit trading markets for common pollutants, like sulfur dioxide and carbon dioxide. While the per unit value of a permit typically fluctuates, it might be too low to adequately represent the total value of all permits across the market because it is simply a marginal value representing an intersection between the supply and demand curves in a competitive market—if a single firm were offered the opportunity to purchase all permits, they may value those permits at a larger magnitude, as this would allow them to assert control over the market and control the supply of permits to other firms.

For nonmarket ecosystem services, several methods may be employed to monetize the value of ecosystem services, summarized in Figure 2. While these methods are often used by researchers and policy makers to generate a best estimate of the value of a particular ecosystem service, it is important to remember that they are just estimates. Generating a value for a non-market good requires many assumptions, leading to inherent uncertainties in the valuation.

Figure 2: Methods for Monetary Valuations of Ecosystems and Examples of their Application (adapted from Daly and Farley, 2011: 461; Farber, 2002: 389-390)

Hedonic Pricing	Estimates economic values associated for ecosystem services that directly affect the market prices of some other good (but not as a production factor): the market value of beachfront property compared to inland property, *ceteris paribis*
Travel Cost	Estimates economic values associated with ecosystems or sites that are used for recreation, assuming the value of a site is reflected in how much people are willing to pay to visit the site (value assigned based on this method represents the minimum that the ecosystem or site is truly worth): total cost of traveling to a national park, including gas, air or train fair, lodging, etc.
Damage Cost Avoided, Replacement Cost, and Substitute Cost	Estimates economic values based on the costs of avoided damage resulting from lost ecosystem services, the costs of replacing ecosystem services to maintain a given level of service, or the costs or providing substitute services: human health impacts of pollution, cost of building a seawall to protect against coastal erosion, cost of waste water treatment plants as a substitute for natural wetlands, etc.
Contingent Valuation	Estimates economic values for virtually any ecosystem service (especially to evaluate non-use or "passive use" values) by asking individuals to directly state their willingness to pay for a specific ecosystem services based on a hypothetical scenario: how much an individual is willing to pay for the ability to catch an additional fish, how much an individual is willing to pay to protect an old growth forest against logging and development
Contingent Choice	Estimates economic values for virtually any ecosystem service by asking individuals to make tradeoffs between sets of ecosystem services or characteristics (without directly asking for willingness to pay), then inferring the willingness to pay based on the tradeoffs that include cost as an attribute: asking an individual whether she would prefer to hike in a pristine forest or one that has been recently logged
Benefit Transfer	Estimates economic values by transferring existing benefit estimates from studies already completed for another location or issue: using a published calculated value for waste treatment ability of a wetland and applying it to the valuation of another wetland

2.3 Benefit Cost Analysis, Discounting, and Net Present Value calculations

2.3.1 Benefit Cost Analysis[2] and Planning

Benefit cost analysis is intended to demonstrate objectivity in decision making processes, and can be used at a variety of different levels, from the individual deciding whether or not to purchase a house to policy decisions regarding federal financing for low income housing. In order to improve transparency, many governmental agencies employ this evaluation method to clearly show the costs and benefits associated with a variety of potential options for a given decision, thus allowing the decision to be backed up by numbers. Though federal directives from the Office of Management and Budget are a bit vague, the use of benefit cost analysis and its implementation should aim to "promote efficient resource allocation through well-informed decision-making by the Federal Government" (Office of Management and Budget, 1992). Some examples of government agencies that employ a formal benefit cost analysis approach include the U.S. Army Corps of Engineers and Bureau of Land Reclamation. Benefit cost analyses have some degree of uncertainty associated with estimated values of non-market goods and rarely include all potential impacts of the project in question (Office of Management and Budget, 1992).

One of the underlying economic principles behind this type of analysis is the concept of Pareto optimality. A Pareto efficient decision is one in which at least one stakeholder is made better off, while no other stakeholder is made worse off—so long as no one is harmed and at least one party experiences an increased benefit, the decision or exchange will be Pareto efficient (Varian, 2006: 15-17). Ideally, policy makers should strive for the condition of Pareto optimality, which

[2] Benefit Cost Analysis is also referred to by some as Cost Benefit Analysis. While the use of the term Benefit Cost Analysis may indicate an author's desire to emphasize benefits over costs, the terms refer to an identical analytical process.

maximizes efficiency such that no party or stakeholder can be made better off without compromising the welfare of another party.

2.3.2 Dealing with Future Values: Discounting

When considering the value of a particular good or service over time, it is important to recognize that there is a difference between present value and future value. As humans, we preferentially chose to consume in the present instead of saving for the future—something that we can have today is worth more than the same amount in 20 years. This is evident in the application of interest rates for bank accounts and government bonds: without some factor to adjust the future value of an investment upward, there would be no incentive for an individual to invest $100 today knowing that the gradual inflation of the dollar would mean that his initial $100 would in fact be worth less than $100 in some future year. To deal with the economic implications of this pure time rate of preference and its subsequent impact on opportunity cost, economists, researchers, and policy makers rely on discounting (Daly and Farley, 2011: 315; Kolstad, 2011: 119-120). Mathematically, discounting is quite simple, and represents the inverse of an interest calculation. Given a future cash flow or benefit[3] X in year t with a presumed interest rate r, the present value of the cash flow or benefit can be calculated as follows:

$$PV = X_t \, / \, [(1 + r)^t]$$

[3] It is possible to apply discounting to a negative cash flow or cost. However, for the purpose of clarity of the examples presented, only benefits will be addressed. Operating under the assumption of Pareto optimality, a decision maker will likely disregard a particular policy option which would result in a negative impact, unless he is forced to choose the least negative option out of a set of exclusively negative options (for example, if a regulatory framework exists that requires action regardless of whether the cost exceeds the benefit, thus resulting in a net cost for any given option). The above equations can also be modified to generically represent benefits and costs, with X_t further defined as the difference between calculated benefits and costs for year t (the net benefit or cost for year t).

This will equation will remain true for any given year. Note that, mathematically, dividing by a number is equivalent to multiplying by its inverse, and thus the equation can take the following form:

$$PV = X_t * 1/[(1+r)^t]$$

The second term in this equivalent expression is known as the discount factor. As the number of years increases, the denominator will increase, resulting in a smaller discount factor in the far future compared to the near future, provided that the interest rate remains constant. The $(1+r)^t$ term increases exponentially as t increases. When the rate, r, is increased, the calculated present value for any given year will decrease. Due to the structure of the present value equation, a change in the rate will be amplified exponentially over time. Even a seemingly small change, such as 0.5%, may lead to significant differences in the calculated present value, especially for years far into the future.

The generic form of this equation can also be applied to a discount rate that varies over time, simply by replacing the constant r term with a variable expression in terms of t. Depending on this expression, the discount factor may behave differently over time as compared to the basic exponential form, and may subsequently impact the calculated present value for a given future year.

2.3.3 Cumulative Value over time: Net Present Value

Discounting provides a method to assess the present value of future cash flows or benefits, but another step must be taken to determine the total value of the cash flow or benefit over time.

Mathematically, the net present value is determined by calculating a summation of the discounted present values for all years over the time period of analysis, as follows:

$$NPV = \sum_{0}^{t} [X_t \; * \; 1 / [(1 + r)^t]]$$

Benefit Cost Analysis relies on this net present value calculation to assess the total value over a given time period. Again, should a non-constant discount rate be applied that varies with time, the r term can be replaced with this discounting expression, provided it is a function of t. If the calculated net present value of Policy 1 is greater than that of Policy 2, then Policy 1 should be chosen to satisfy the Pareto criterion.

2.4 Current Applications of Ecosystem Service Valuations

2.4.1 Application of Ecosystem Service Valuations in Decision Making

While ecosystem service valuations should provide a good estimate of benefits for a benefit cost analysis, they are not consistently employed in decision making processes. Overall, there seems to be a general lack of consistency in how ecosystem service valuation projects are implemented, both from a design perspective as well as their applied use in policy decisions (Laurans *et al*, 2013). Different valuation estimates are utilized, with no set standard approach to economic value estimation tools. Assessments of previously conducted valuations indicate a number of shortcomings and inconsistencies in the methodology surrounding this approach, which may contribute to a limited applied use of ecosystem service valuations as the primary driver in the decision making process:

> "Reality indicates that society needs a mutual effort of understanding among policy makers, stakeholders and scientists to establish an effective dialogue. While problem solving and governance in society is not possible without the intervention of multiple actors and policy makers, successful decisions regarding land use may not be viable without the support of the best scientific knowledge available. The argument that current methods for valuing ecosystem services are still imperfect is indisputable, but they rely on the best body of knowledge that is available. To reduce uncertainty around valuation in coming years, the scientific community must make a considerable effort to reconcile the best-known methods of economic valuation to the emerging bio-physical ones… Combination and complementation between economic and bio-physical valuation will probably be the best way to minimize uncertainty." (Viglizzo *et al*, 2012: 82)

Instead of being a central part of the decision, ecosystem service valuations, more often than not, are conducted in order to comply with a regulatory requirement or are simply conducted after a decision has already been made in order to provide justification for the decision (Laurans *et al*, 2013). One potential reason for this discrepancy is due to uncertainties surrounding the discount rate.

2.4.2 Discounting Decisions

Current discounting practices for benefit cost analysis vary widely. For most federal programs, the particular office or agency may use its own discretion to determine an appropriate discount rate. The Office of Management and Budget suggests that the chosen rate should not be less than 7.0%, and that is it acceptable to use higher discount rates depending on the nature of the analysis (Office of Management and Budget, 1992).[4] This rate is used in the context of an exponential discounting equation. While the Office of Management and Budget does publish yearly updates with specific discount rates based on the nominal and real interest rate of U.S.

[4] This rate is actually the real discount rate. The nominal discount rate, which includes inflation, will be higher. The real discount rate represents the degree of discounting after inflation has already been accounted for.

Treasury Bonds, these values are intended for monetary analysis of lease-purchase agreements and cost-effectiveness analysis, not for regulatory analysis or benefit cost analysis for public investment (Office of Management and Budget, 2014). The discount rate for benefit cost analysis of federal projects remains at 7.0%, despite this figure being more than 20 years old.

The National Oceanic and Atmospheric Administration, which conducts many benefit cost analyses that address ecosystems and restoration projects, has promoted its own policy of a 3.0% discount rate to more adequately represent the social rate of time preference (National Oceanic and Atmospheric Association, 2014).[5]

The Army Corps of Engineers, which does extensive work involving wetlands, has its own set of discounting procedures. Discount rates for project evaluations are published annually and calculated based on the market yield for U.S. Treasury securities. For the 2014 fiscal year, the Army Corps of Engineers has adopted a 3.5% discount rate for water related projects (U.S. Army Corps of Engineers, 2014).

2.5 Problems With the Current Model: Economic Theory

2.5.1 Non-Market Goods

Exponential discounting, in which the discount rate remains constant over time, is well suited for private or market goods, especially when there is a high degree of knowledge surrounding future

[5] The social rate of time preference in this case was calculated based on the real Gross Domestic Product growth over a select period of years, and represents the productive capacity of industry within the Unites States. The social rate of time preference, or social discount rate, is a conversion factor used for present value calculations that represents the collective ethical judgment of society instead of an individualized economic judgment, like the market interest rate (Kolstad, 2011: 120-121).

predicted values or cash flows. Take for example a developer's decision between constructing two different apartment buildings. A *pro forma* for each building will include reasonably well-predicted future cash flows from rent, as well as expenditures that may remain constant or vary over the years for analysis. These predicted values are based on known market values of goods, such as construction materials, as well as market prices for housing in that particular area, both of which are rival and excludable. A benefit cost analysis comparing the two building options would likely be conducted over the usable life of the buildings, probably 30 to 50 years depending on the market. After this selected time period of analysis, it is assumed that the building will have little economic value, due to functional obsolescence, more stringent building code requirements, overall deterioration, etc. A constant discount rate is chosen, typically the internal rate of return for the project, which serves to account for the opportunity cost of investing in the building.[6] Year after year, the present values of the future cash flows decline.

Unfortunately, the valuation of ecosystem services does not fit well into this private good discounting model—if we acknowledge that ecosystem services do not behave as market goods, then why do we discount them as such? The nature of the asset should determine the type of discounting that is used.

2.5.2 False Assumptions of Diminishing Returns

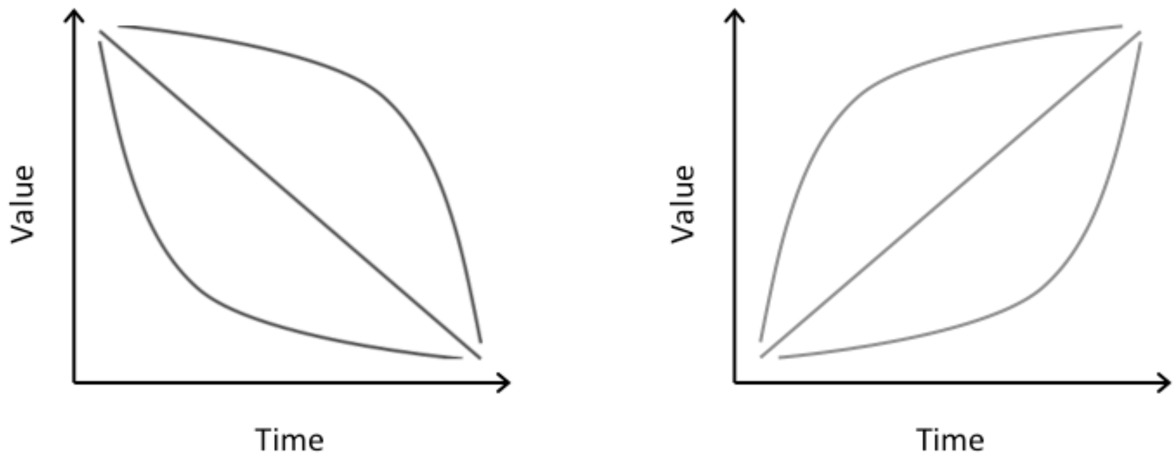
Unlike the apartment building example above, ecosystems should not reach a point of functional obsolescence. Provided they are reasonably well protected and not subject to near-complete degradation, ecosystems should remain functional into perpetuity. In fact, ecosystems may

[6] The internal rate of return is the discount rate for which the net present value of all benefits from the project is equal to the net present value of all costs incurred by the project (i.e. when the difference between net benefits and net costs is equal to zero).

become more productive if they are conserved and protected, allowing natural functions and processes to be maximized. From an anthropocentric perspective, this increase in productivity of the ecosystem will lead to an increase in economic value for a particular ecosystem service, especially if that service serves as a production input in the economy (timber, fish, waste treatment capacity, etc.). Healthy ecosystems are capable of self replenishing, provided they have not been damaged to an extent such that some species have fallen below their minimum viable population levels, and will exhibit increasing returns for natural capital.

Returning to the classical economic theories of Adam Smith, we find that this idea of increasing returns is reasonable. Smith noted the presence of increasing returns when analyzing the influence of technological development in manufacturing and the division of labor in the Eighteenth Century, stating that "the division of labor, however, so far as it can be introduced, occasions, in every art, a proportionable increase of the productive powers of labor" (Smith, 1776: 18). While Smith's examples are specific to labor division during the Industrial Revolution, this concept can be broadly applied to any number of inputs in the production function. In the case of ecosystem services, preserving function in one time period may lead to an increase in that function for future periods, thereby leading to an increase in future values. If diminishing returns (or constant returns for that matter), dominated the mechanisms of ecosystem services, ecological and biological growth would not be possible. The ecosystem, independent of any intervention, would decline, or at best remain constant over time. Biological and functional capacity for growth inherently contradict this underlying assumption of decreasing returns that is associated with exponential discounting. Figure 3 graphically demonstrates the difference between the diminishing returns and increasing returns.

Figure 3: Conceptual Representation of Diminishing Returns (left) and Increasing Returns (right) shown as a function of value over time



2.5.3 Bounded Rationality, Incomplete Information, and Future Uncertainty

As previously stated, the driving factor behind the concept of discounting is the fact that humans value things less in the future compared to the present. Exponential discounting results in a substantial decline in value, especially in the far future, but it doesn't adequately describe human behavior:

> "If you heard global warming was going to result in the deaths of 50 million Bangladeshis in 125 years, would that make you feel only half as bad as finding out it would actually kill those 50 million Bangladeshis in 100 years? If you are like most people, you would feel equally as bad in either case, yet influential economic models of the impacts of global warming really do assume we would care only half as much about those deaths if they occurred 25 years later." (Daly and Farley, 2011: 319)

While the above example is a bit extreme, it does illustrate a fundamental problem with exponential discounting. If rationality is defined by the exponential discounting model, then the above example demonstrates that individuals are bounded in their rationality at a particular threshold when considering the far future.

Approaching uncertainty with regards to the future or a lack of complete information necessitates the use of caution. Because it is difficult, if not impossible, to guarantee access to complete information about ecosystem functions and services, any environmental management policy or development decision should leave a margin of error (Daly and Farley, 2011: 415). From an investment perspective, high degrees of uncertainty encourage the use of high discount rates to account for volatile cash flows or markets. In the event of information uncertainty regarding the future, investors require a higher internal rate of return to adequately compensate them for their risk. The economic rationality behind ecosystem services should behave in an opposite manner: because humans rely heavily on ecosystem services, future uncertainty would therefore lead to an increased desire to protect resources and ecosystem functions in order to guarantee continued future benefits. This is also represented by the imposition of increased scarcity, which in turn increases the relative value of ecosystems and their services (Sterner and Persson, 2008: 62).

2.5.4 Intergenerational Equity

The inherent nature of exponential discounting disadvantages future generations with regards to their inheritance of natural resources and ecosystem services. In discussing Rawl's second principle of maximizing social welfare at its minimum level (the difference principle), Arrow notes the implications of intergenerational equity considerations for economic decisions:

> "To what extent is one generation obligated to save, so as to increase the welfare of the next generation? … more recently, we have become especially concerned with the preservation of undisturbed environments and natural resources. The most straightforward utilitarian answer is that the utilities of future generations enter equally with those of the present. Since the present generation is a very

> small part of the total number of individuals over a horizon easily measurable in thousands of years, the policy conclusion would be that virtually everything should be saved and very little consumed, a conclusion that seems offensive to common sense. The most usual formulation has been to assert a criterion of maximizing a sum of *discounted* utilities, in which the utilities of future generations are given successively smaller weights. The implications of such policies seem to be more in accordance with common sense and practice, but the foundations of such a criterion seem arbitrary." (Arrow, 1973: 111)

Arrow acknowledges two important issues in the above quote: some kind of discounting is necessary to allow for consumption in the present and near-future, but the selection of a particular constant discount rate for exponential discounting is somewhat arbitrary. High exponential discount rate functions, like those suggested by the Office of Management and Budget, will subject future generations to a disproportionate loss of ecosystem services. Given the presence of increasing returns for ecosystem services, excess consumption in the present time period will reduce the capacity for future returns, effectively sacrificing more abundant future returns for smaller short term gains, thus reducing the overall welfare of society (Pigou, 1932). Conversely, discount rates that are too low might disproportionate impact the current generation's ability to consume ecosystem services, develop infrastructure, or realize economic growth. If the discount rate is set to an artificially low value (near zero), intergenerational equity might be maximized, but may result in inconsistencies among sectors, forcing the public to choose between healthy future ecosystems and needs perceived as urgent, such as poverty alleviation and disease eradication (Kolstad, 2011: 121). The intergenerational equity challenge requires that an appropriate discount rate be utilized, such that it does not underestimate the interests of future generations, but rather treats the present and the future equally (Chichilnisky, 1996: 233).

2.6 Advantages of Hyperbolic Discounting

Hyperbolic discounting serves as a better representation of human preferences (Green, 2012; Cropper and Laibson, 1998). Unfortunately, hyperbolic discounting is not readily used with regard to benefit cost analysis applications. In order to promote environmental conservation and protection to ensure that future generations have access to ecosystem services, the economic analysis used in decision-making must move from the normative to the positive realm (Kolstad, 2011: 30-38). Quasi-hyperbolic discounting has been shown to retain higher present values in the far future, and, depending on the particular time horizon, may lead to higher net present values for ecosystem restoration projects compared to exponential discounting (Green, 2012). Functionally, hyperbolic and quasi-hyperbolic discounting rely on yearly discount rates that vary over time. Mathematically, the present value of a future benefit or cost under a hyperbolic discounting function is calculated as follows:

$$PV = X_t \ * \frac{1}{[1 + rt]}$$

The nature of this equation leads to a steep slope for small values of t, with smaller slopes for increasingly large values of t. For a given rate r, the present value obtained from hyperbolic discounting is equal to the present value obtained from exponential discounting for the t=1 (year 1).

One of the issues with pure hyperbolic discounting is that it leads to inconsistent consumption plans over time due to the form of the equation—looking to the future, the rational individual with hyperbolic preferences will perceive a low discount rate between two consecutive time periods, but when those time periods come to pass, he will perceive a higher discount rate and alter his behavior to significantly favor the present (Cropper and Laibson, 1998: 1). This inconsistency will manifest for all time periods. As the rational individual moves through time, the shallow, far-future section of the curve will be replaced by the steep near-future section, resulting in the individual choosing to value the current period at an inappropriately large level (for consumption, spending, etc.). Attempts have been made to address this inconsistency. Moving towards a quasi-hyperbolic model in which there is a brief "hold" period, it is possible to alter preferences in such a way some value is still reserved for the future by lowering the rate of return (Cropper and Laibson, 1998: 2). However, this inconsistency is not central to the overall evaluation of the impacts of discount function and rate selection. Because this study aims primarily at exploring the long-term impacts of these decisions, short term discrepancies and inconsistencies should not impact the outcomes of the net present valuations. Additionally, this inconsistency only applies to preferences as they are evaluated over time. Since net present values are calculated for a singular time period in which the cost benefit analysis is taking place, the hyperbolic discounting equation above is appropriate.

Chapter 3: Methodology

Generally speaking, the methodology employed for this study will be considered an exploratory meta-analysis of existing data. Using previously conducted, peer-reviewed ecosystem service valuation studies, the impacts of discount rate selection will be analyzed. This study will focus exclusively on coastal wetlands, as they supply critical ecosystem services in the face of climate change predictions while also representing spatial scarcity. A variety of discount rates and functions will be applied to the dollar value per acre of recent North American coastal wetland ecosystem service valuations, projecting their values over a 200-year time horizon. Overall trends in discounting selections will be explored, and statistical testing will be employed to determine the presence of significant differences between discount functions and rates for both overall net present value and present values for specified years of comparison.

3.1 Justification for coastal wetlands as the ecosystem of interest

In order to isolate the effect of discount rate and function selection on the net present valuation of ecosystem services, it is necessary to restrict analysis to one particular ecosystem. Because wetlands, forests, and grasslands are all functionally different, comparing across ecosystems would result in uncertainty due to discrepancies in the specific ecosystem services provided by each ecosystem.

3.1.1 Recognized Ecosystem Services

Coastal wetlands provide a number of benefits to humans. Specific services provided by coastal wetlands include flood control and storm surge buffering, water purification (quality), water supply, fuel wood, commercial fishing and hunting, recreational fishing and hunting, harvesting of natural materials (timber, etc.), non-consumptive recreation, aesthetic qualities, and the provision of natural habitat and preservation of biodiversity (Camacho-Valdez *et al*, 2013).

3.1.2 Representation of Scarcity: Issues with Mitigation

Coastal wetlands provide a good representation of scarcity in terms of spatial distribution. Unlike riverine or other inland wetlands, coastal wetlands are restricted in location. With the small exception of volcanic islands, the overall length of coastlines globally remains relatively constant. Due to their bio-physical constraints, coastal wetlands cannot be relocated inland as a mitigation measure. Unlike forests, which can be replanted, coastal wetlands are not easily renewed once they have been damaged or degraded. When mitigation is pursued to replace wetlands lost to development or another land use change, there can be a significant lag time and subsequent temporary loss of overall function, as it takes many years for wetland hydrology, soils, and vegetative communities to initially establish or re-establish themselves (BenDor, 2009).

3.1.3 Importance of Future Uncertainty

Coastal wetlands are particularly important in the context of future uncertainty, especially with regards to future climate change scenarios. Climate change predictions indicate that sea levels will rise globally and that storms may increase in severity due to higher atmospheric temperatures (increased ambient energy). Subsequently, coastal wetlands may become more valuable as the effects of climate change manifest. Unfortunately, the historical de-watering of wetlands to make land more suitable for agriculture and urban development has reduced the overall capacity of coastal wetlands to provide their natural functional benefits:

> "Coastal wetlands are some of the most productive ecosystems in the world, supporting diverse natural functions and providing important services to human societies. In this context, strategies have recently been developed to maintain these coastal wetlands in a sustainable way, however, wetlands are under pressure, particularly due to land use changes, because they have traditionally been treated as areas of low economic value or even as risky areas for human health. As a result, wetlands have suffered some loss and substantial habitat alteration, which are associated with high social costs." (Camacho-Valdez *et al*, 2013: 1)

Recent hurricane damage along the eastern coast of the United States during "Superstorm Sandy" has exemplified the importance of coastal wetlands and barrier islands as natural capital for protection against storm surge and flooding.

3.2 Discounting Scenarios: Selection of Discount Rates and Functions

Discounting scenarios will be defined based on both function and rate, described below.

3.2.1 Exponential Discount rates

Exponential discount rates will be based on the policies of the Office of Management and Budget, the National Oceanic and Atmospheric Administration, and the U.S. Army Corps of Engineers. A 0% real discount rate will be also used to show the impact of inflation. Because the data obtained for this study will be in nominal dollar terms (i.e. all future benefits are presumed equal and not pre-adjusted for inflation), an inflation adjustment must occur to transform the real discounted rates below into nominal rates. As of March 2014, the Bureau of Labor Statistics has estimated the U.S. inflation rate at 1.5% (Bureau of Labor and Statistics, 2014a).

Table 1: Summary of Real and Nominal Discount Rates Selected for Analysis

Source	Real Discount Rate	Nominal Discount Rate
Office of Management and Budget	7.0%	8.5%
U.S. Army Corps of Engineers	3.5%	5.0%
National Oceanic and Atmospheric Administration	3.0%	4.5%
(Base Line)	0%	1.5%

3.2.2 Hyperbolic Functions

The above real discount rates will also be used in the context of the hyperbolic discount function, so rate function selection can be compared across selected rates.

3.3 Selection of Case Studies

3.3.1 Geographical Restriction

Coastal wetland ecosystem service valuations used for this study will be geographically restricted to those conducted in North America. This will accomplish several goals:

1) Preferentially select for peer-reviewed journal articles that were originally written in English.
2) Reduce functional variations in ecosystem services across locations.
3) Assure that the articles are published in reputable journals.[7]

[7] In recent years, several new scholarly journals have surfaced in developing countries, such as China. Some of these journals have limited editorial oversight and have been engaging in predatory behavior with regard to recruiting academic articles, attempting to exact a publication fee from authors. This issue is of particular concern because Chinese scholars have published many ecosystem service valuations for particular wetlands in China over the past few years, and without a substantive investigation into the specific journal of publication, it would be difficult to ensure the validity of the journal and its published studies.

4) Assure that an adequate number of valuations can be identified for inclusion in the study.[8]

3.3.2 Temporal Restriction

Components of ecosystem service valuations have evolved over the years. Increased scientific knowledge and collaboration across disciplines like ecology and economics have allowed researchers to identify increasingly specific services with more accurate estimates of their values. Naturally, the earliest ecosystem service valuations may be less reliable compared to more recent valuations. In order to reduce some of the threats to internal validity for this analysis, selection of coastal wetland ecosystem service valuations will be restricted to the past 15 years of published, peer-reviewed valuations.

3.3.3 Search Criteria

Using the University of Washington's library catalog, a search will be performed using combinations of the following words and phrases:

> "ecosystem services", "ecosystem valuation", "coastal wetlands", "environmental valuation", "wetlands"

It is important to note that the choice of specific keywords can have an impact on what articles will be returned as a result of the search (Laurans *et al*, 2013: 210). It is highly unlikely that any given combination of keywords will return all relevant studies.

3.3.4 Assumption of Correct Valuations

A key assumption for this study is that the valuations calculated within the selected peer-reviewed articles are correct. There is no strict requirement of what must be incorporated into an

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[8] As of 2011, the United States and China had the largest number of peer-reviewed, published ecosystem service valuations, with Canada and Mexico closely trailing (Seppelt *et al*, 2011: 631)

ecosystem service valuation, nor any guarantee that all services have been properly identified and quantified. Several key issues surrounding these inconsistencies are the biophysical reality of data collection and derivation (i.e. the actual possibility of being able to clearly define and quantify a given ecosystem service and its subsequent value), trade-offs for both local and off-site that may affect the overall valuation, and the need for a comprehensive involvement of stakeholders who may present additional information or offer additional aspects for review and quantification for a given economic approach (Seppelt *et al*, 2011). All coastal wetland ecosystem service valuation studies that have been returned using the aforementioned search criteria are assumed to be correct and valid based on the scrutiny of a standard peer-review process. Presumably, studies in which questionable ecosystem service identification and quantification methods have been employed would not pass through this vetting process, and therefore would not be published.

3.4 Data and Transformations

3.4.1 Units of Analysis

The unit of analysis for this study is the individual coastal wetland ecosystem service valuation selected by the method described in Section 3.3. Only one dependent variable will be associated with each unit of analysis, and will be defined as the calculated dollar value of all explicitly stated ecosystem services per acre of the coastal wetland.

3.4.2 Temporal Adjustment of Raw Data

In order to eliminate any inter-temporal disparities between case studies that were published in different years, a time dependent conversion on the calculated dollar value per acre is needed.

There are two main methods to accomplish this adjustment: a specific factor conversion approach and an inflationary approach.

Given that the focus of this study is the actual impact of discounting on future ecosystem service values and net present valuations, adjusting calculates per unit area values by the inflation rate may not be ideal. A price adjustment factor could be used to transform all values from previous time periods to current values. This price conversion factor could be determined by a direct proportional comparison of market prices or replacement cost in the given year of the ecosystem service valuation to that of the current year. However, many ecosystem service valuations rely on the benefit transfer method. As such, they do not compute individual values for specific ecosystem services. Instead of calculating the total waste treatment capacity of a wetland and then multiplying that capacity by its replacement cost (i.e. the cost for treating that same amount of waste at a waste water treatment facility), they utilize published values from existing studies, thus preventing one from calculating a conversion factor to be applied to the total value of the wetland.

Adjusting the data by inflation is a more realistic option. Such an adjustment is possible for any valuation methodology, and therefore works even if the sample valuations were conducted using the benefit transfer method. Inflation adjustments will be made using an inflation calculator maintained by the Bureau of Labor Statistics, which utilizes the Bureau's recorded inflation rates over time (Bureau of Labor Statistics, 2014b). If the years of initial submission and publication differ for a particular ecosystem service valuation, the year of submission will be assumed to be the year in which the valuation took place, unless otherwise specified.

3.4.3 Data Format

After all appropriate coastal wetland ecosystem service valuations have been gathered and transformed as described above using Microsoft Excel, the modified data will be saved as a .csv file so that it can be easily read into R.

3.5 Future Value and Net Present Value Calculations for Discounting Scenarios

Once data has been formatted correctly, it will be read into R, an open-source coding language that has become increasingly popular for social science statistical analysis and data visualization. The full version of R code can be found in Appendix B.

3.5.1 Coding for Discounting Scenario Application

The previously described discounting scenarios will be applied using the current period as year zero for calculations. Because discounting is a simple mathematical transformation, discounted future values can be calculated for any number of future years. For the purposes of limiting the size of the generated discounted datasets, the number of years used for calculations will be limited to 200. Should it be necessary to analyze the impacts of discounting rate and function selection in the very far future, the R code found in Appendix B can be easily modified.

3.5.2 Designated Years for Net Present Value Calculations

Cost-Benefit analysis requires a comparison to be made within a finite, designated time frame. The length of time for the comparison typically depends on the nature of the good or service in question. For this study, the net present value will be calculated for 20, 50, 100, and 200 years. While these selected years may seem arbitrary, they attempt to represent varying degrees of future uncertainty and the potential degree of lasting impacts that a particular land use decision might have. Calculation of net present value will be accomplished by taking the sum of the discounted values over the entire designated time period.

3.6 Statistical Analysis

For the purpose of statistical testing, the series of data generated from each discounting scenario will be considered a sample.

3.6.1 Descriptive Statistics

Descriptive statistics will be calculated to provide a snapshot comparison of the discounted present value in years 20, 50, 100, and 200. Descriptive statistics will be calculated for each discounting scenario on the basis of net present value for the specified time periods above.

3.6.2 Statistical Testing

In order to provide for more than just a qualitative analysis of the effects of the various discounting scenarios, statistical testing will be employed. Using an unpaired student's t-test, average values will be compared between exponential and hyperbolic functions for each discounting scenario to determine whether there is a statistically significant difference between the means with 95% confidence (alpha = 0.05). In the case of t-test failure at the 95% confidence level, testing will be repeated at the 90% confidence level (alpha = 0.1) and 80% confidence level (alpha = 0.2).

Chapter 4: Results

Using the methodology presented in Chapter 3 and the R script code detailed in Appendix B, present values for each discounting scenario were projected to year 200. The following sections describe the numeric outcomes of the analysis and present the outcomes in graphical form.

4.1 Search Results and Data Summary

The web-based search of the University of Washington library database of peer-reviewed articles, as described in Section 3.3.3, returned fewer appropriate articles than expected. Upon further inspection, five articles were deemed appropriate. Two of the articles were meta-analyses of existing literature, and estimated upper and lower bounds for the per acre value of coastal wetlands. Another article estimated the value of coastal wetlands using two methods, willingness to pay and willingness to avoid, returning two separate valuations. The year of valuation, value per acre during the year of valuation, and inflation-adjusted current value for the data are summarized in Table 2. A summary of published values, data transformations, and bibliographical information can be found in Appendix A.

Table 2: Summary of Data with Inflation-Adjusted Values per Acre

Year of Valuation	Estimated Value per Acre	Inflation-Adjusted Value per Acre (2014 dollars)
2013	$8,974	$9,133
2003	$7,274	$9,372
2004	$6,527	$8,191
2004	$6,131	$7,694
2008	$2,040	$2,246
2008	$3,923	$4,320
2009	$3,938	$4,352
2009	$20,993	$23,198

4.2 Analysis of Present Value Impacts

Using R Studio, and open source program, and R code in Appendix B, the current inflation-adjusted values per acre for coastal wetlands were projected to year 200 using the discounting scenarios described in Section 3.2.

4.2.1 Trends in Present Value: Comparing Exponential and Hyperbolic Projections

Because discounting is a mathematical transformation with a variable term in the denominator, present values must decrease as the number of years from the present time period increases. This is true for both the exponential and hyperbolic discounting functions, but the effect of the increasing time variable is not equal across the functions. Figures 4 through 7 summarize the average present values of the data over time, comparing the effect of exponential and hyperbolic discounting for each selected discount rate. A change in present values for both the exponential and hyperbolic discounting functions can be observed for each applied discount rate, and for all scenarios the exponentially discounted present value is less than the hyperbolically discounted present value after year 1.

Figure 4: Average Present Value given a 7.0% real discount rate projected over 200 years using exponential and hyperbolic discounting functions

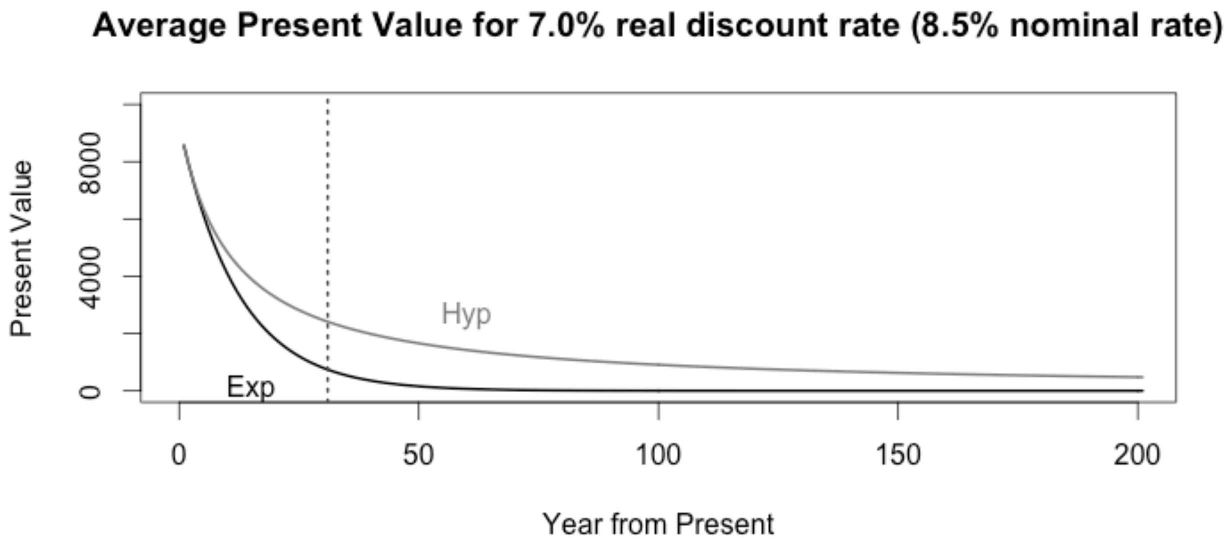


Figure 5: Average Present Value given a 3.5% real discount rate projected over 200 years using exponential and hyperbolic discounting functions

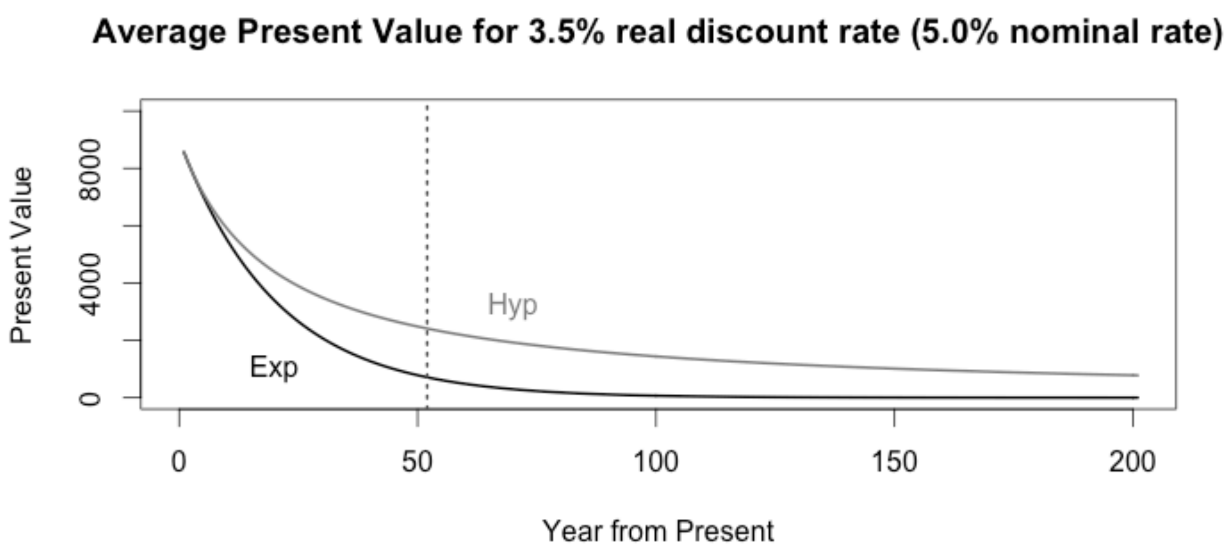


Figure 6: Average Present Value given a 3.0% real discount rate projected over 200 years using exponential and hyperbolic discounting functions

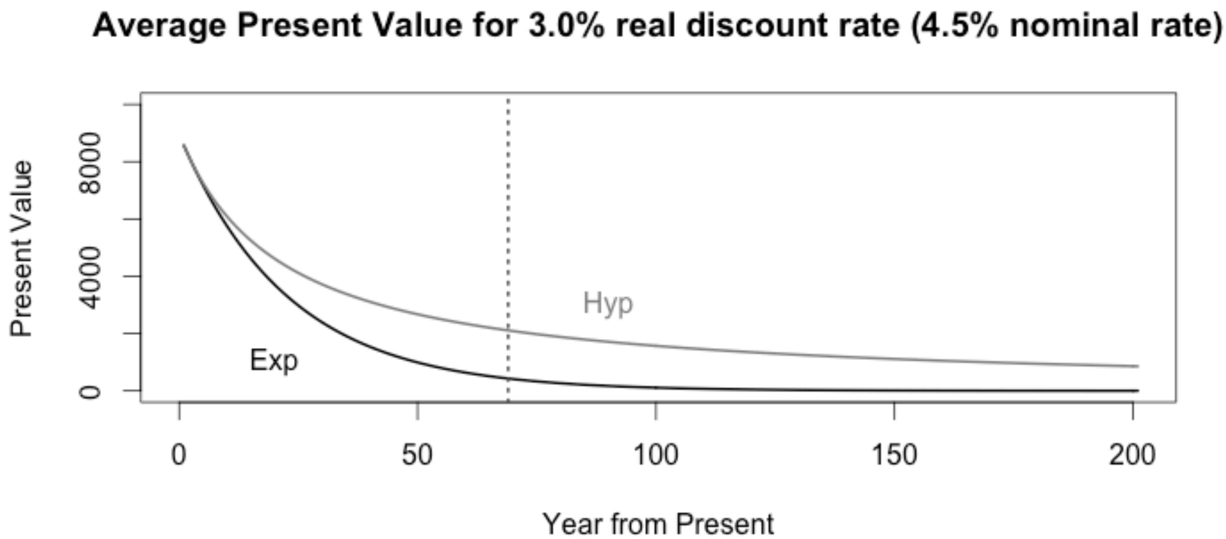
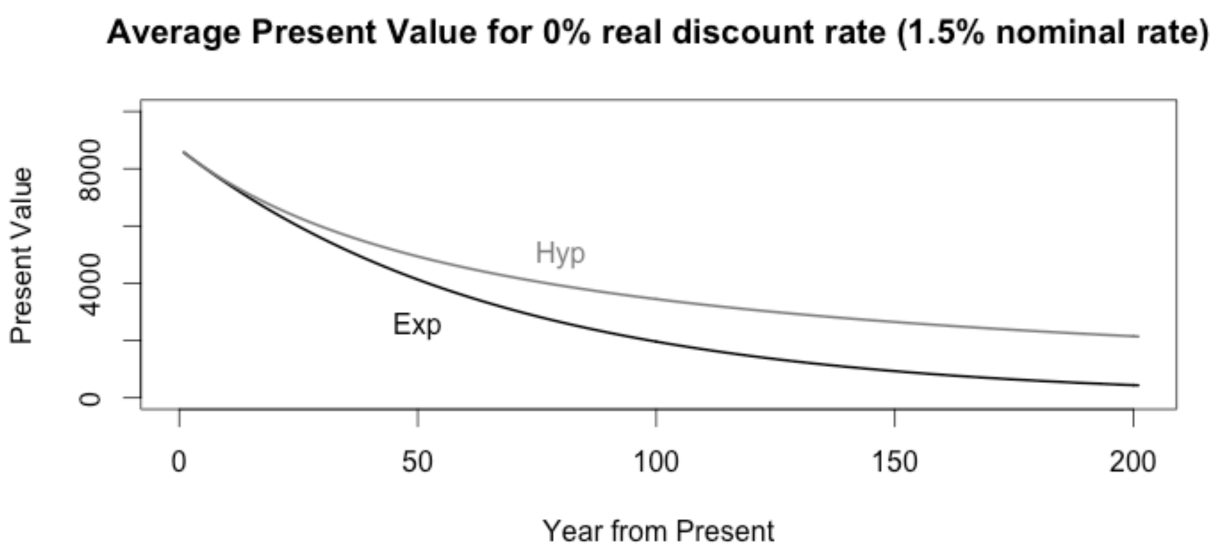


Figure 7: Average Present Value given a 0% real discount rate projected over 200 years using exponential and hyperbolic discounting functions



The shift in the exponential and hyperbolic curves for the projected present value for each discount rate also leads to an apparent trend in the year at which the maximum difference between the curves occurs: as the discount rate decreases, the year of maximum difference increases. This year is indicated in Figures 4 through 7 as a dashed line. Higher discount rates result in this maximum difference occurring in the near-term, while lower discount rates lead to this maximum difference occurring in the far future. For the 7.0%, 3.5%, and 3.0% real discount rates, the maximum difference between exponentially and hyperbolically calculated discount rates occurs within the projected 200-year time horizon. In the case of the 0% real discount rate, a maximum difference does exist, but does not occur within this time frame. The years at which the maximum occurs for each discounting scenario are summarized in Table 3.

Table 3: Summary of the Year at which the maximum difference between exponentially and hyperbolically discounted present values occurs

Discount Rate (real)	Year of Maximum Difference
7.0%	31
3.5%	52
3.0%	69
0%	200+

4.2.2 Trends in Present Value: Comparison Across Discount Rates

Looking specifically at the impact of the discount rate, the Figures 8 and 9 provide a graphical summary of the change in present value over time as a function of the discount rate selection. Figure 8 displays this trend for exponential discounting, while Figure 9 illustrates this trend for hyperbolic discounting. The exponential discounting function appears to have a more substantial decrease in present values in the relatively near-term years, after which values asymptotically approach zero for far future values for 7.0%, 3.5%, and 3.0% real discount rates. The baseline

(0% real discount rate) appears to be following this trajectory, but has not yet reached this asymptotic approach to zero in the 200-year projection. For the hyperbolic discounting function, none of the average present values for the selected discount rates asymptotically approach zero over the projected time period, thus retaining present value even in the far future out to year 200. Mathematically, these values will eventually approach zero, but on a much longer time horizon. For both the exponential and hyperbolic discounting functions, lower discount rates lead to higher future present values, though this trend is much more pronounced in the case of the hyperbolic function, especially in the far future beyond 50 years.

Figure 8: Average Present Value compared across 7.0%, 3.5%, 3.0%, and 0% real discount rates using an exponential discounting function

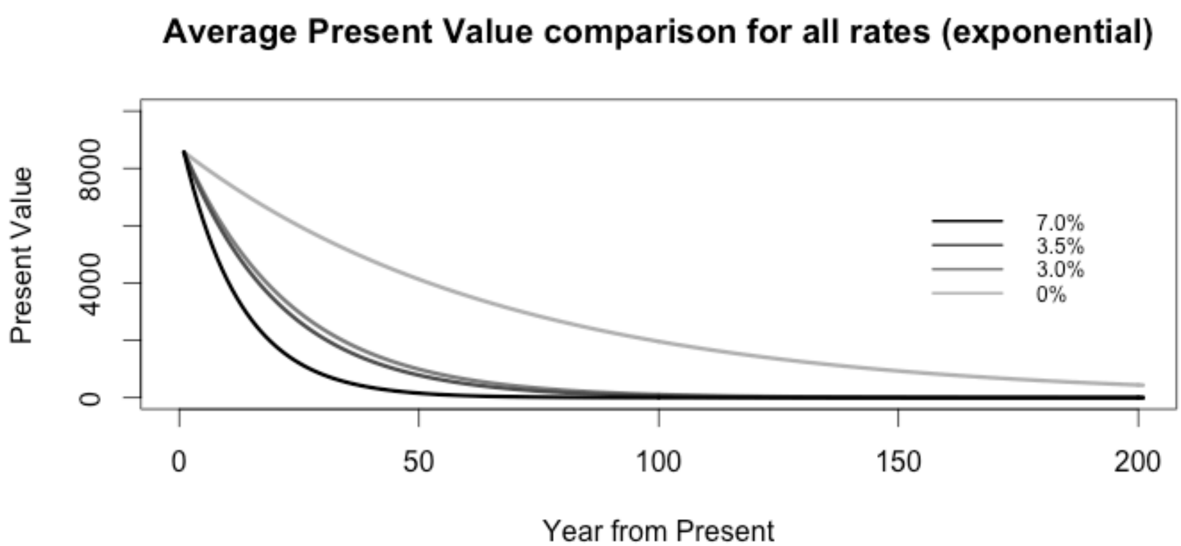
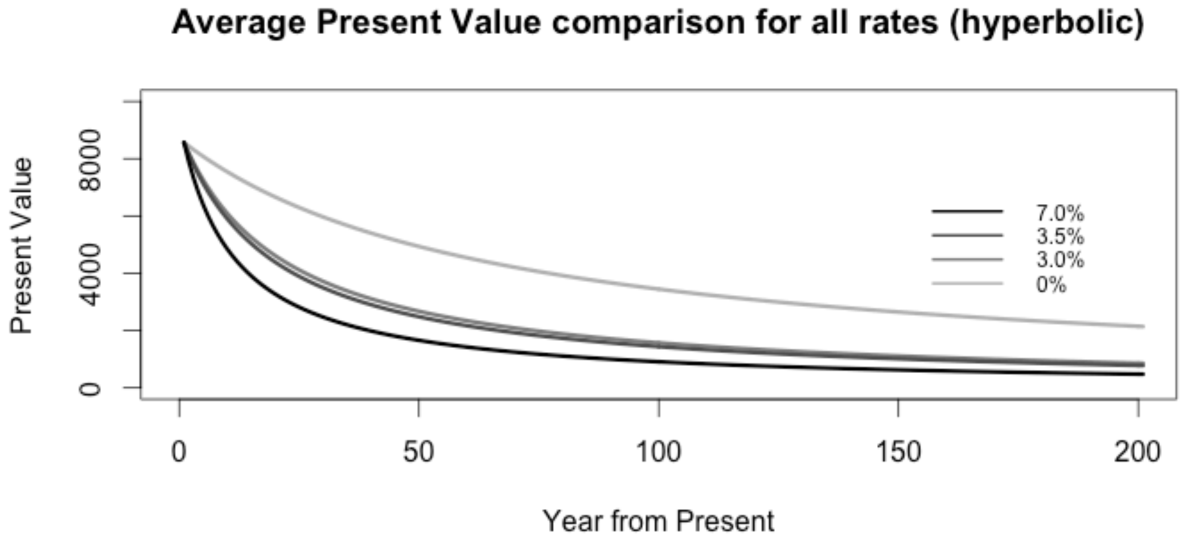


Figure 9: Average Present Value compared across 7%, 3.5%, 3%, and 0% real discount rates using a hyperbolic discounting function



4.2.3 Approaching an effectively zero value

As the projected present values decline over time, the values for some scenarios dwindle to a small fraction of their original current time period value. When comparing values on the magnitude of thousands of dollars, a small value, such as $5, may be viewed as trivial for the purposes of decision-making. For the purposes of this investigation, an "effectively zero" value was defined as being less than 1% of the original present value for the current year. Table 4 shows the year at which each discounting scenario reaches this effectively zero value, as well as when the present value drops below 10% of its original value for comparison.

Table 4: Summary of year at which the present value falls below 10% of the current value and when the present value effectively reaches zero for each discounting scenario

Discounting Scenario	Year at which discounted present value drops below 10% of current value	Year at which discounted present value reaches the "effectively zero" value (<1% of current value)
Exponential @ 7.0%	29	57
Exponential @ 3.5%	48	95
Exponential @ 3.0%	53	105
Exponential @ 0%	155	N/A
Hyperbolic @ 7.0%	106	N/A
Hyperbolic @ 3.5%	180	N/A
Hyperbolic @ 3.0%	200	N/A
Hyperbolic @ 0%	N/A	N/A

For both the exponential and hyperbolic discounting scenarios, the year at which the discounted present value drops below 10% of the current value increases as the discount rate decreases. In the case of hyperbolically discounted baseline projection in which the real discount rate was set to 0%, the present value does not drop below 10% within the 200-year time horizon. For the 3.0% hyperbolic discount scenario, the discounted present value falls below 10% of the current value at year 200, the very end of the time horizon. Comparing between the exponential and hyperbolic discount functions for all rates, the hyperbolically discounted present value projections retain a higher value into the future, falling below 10% of the current value well after this point is reached by the exponentially discounted projections for each rate (if at all). In terms of the effectively zero values for the discounting scenarios, this point is only reached for the non-zero exponential discounting scenarios.

4.3 Analysis of Net Present Value Impacts

Benefit Cost Analysis makes use of net present value calculations in its methodology, and as such it is important to understand the trends in the net present value for each discounting scenario. Table 5 summarizes the average net present values calculated for each scenario at 20, 50, 100, and 200 years.

Table 5: Average Net Present Values for all Exponential and Hyperbolic Discounting Scenarios calculated for 20-, 50-, 100-, and 200-year time horizons

YEAR	20	50	100	200
Exponential @ 7.0%	$89,600	$107,602	$109,279	$109,307
Exponential @ 3.5%	$115,280	$164,893	$178,526	$179,818
Exponential @ 3.0%	$119,954	$177,790	$196,525	$198,829
Exponential @ 0%	$155,583	$308,274	$450,639	$550,384
Hyperbolic @ 7.0%	$105,984	$172,212	$231,597	$295,768
Hyperbolic @ 3.5%	$125,161	$220,092	$311,896	$415,382
Hyperbolic @ 3.0%	$128,700	$229,920	$329,495	$442,911
Hyperbolic @ 0%	$157,359	$326,211	$529,098	$796,774

Mathematically, net present value is a summation of present values over a given time period. Therefore the asymptotic approach to zero of the exponentially discounted present values as shown in Figure 8 (especially for the non-zero real discount rates) leads to minimal changes in the net present value for far future values. This is especially apparent for the 7.0% exponentially discounted scenario, in which the change in net present value from years 100 to 200 is a mere $28. The change in net present value between years 100 and 200 is also rather small for the 3.5% and 3.0% exponentially discounted scenarios, at $1,292 and $2,304, respectively. As for the 0% exponentially discounted net present value, this scenario results in a substantially larger difference between the net present values at 100 and 200 years, equaling $99,745. As for the hyperbolically discounted net present values, even the 7.0% discounting scenario retains high enough present values in the far future to result in a $64,171 difference between the net present value at years 100 and 200. This difference between the net present value at years 100 and 200 for the 3.5%, 3.0%, and 0% hyperbolic discounting scenarios is equal $103,486, $113,416, and $267,676, respectively.

Comparing the effects of the discount function selection for each discount rate, Figures 10 though 13 show the loss of net present value over the 200-year time horizon. The summation of present values over the 200 years time horizon is mathematically equivalent to the area under the present value curve. The black, denser hatching represents the average net present value at 200 years using the exponential discount function. The gray, less dense hatching represents the additional average net present value realized by utilizing the hyperbolic discount function. The total average net present value calculated using the hyperbolic discount function is represented by the area under the gray hyperbolic present value curve, and thus includes both the gray and black hatched areas. In the case of the 7.0% discount rate, the exponential discounting function results in a loss of $186,461 in average net present value over 200 years compared to the hyperbolic discounting function. For the 3.5%, 3.0%, and 0% discount rates, this loss is equal to $235,564, $244,082, and $246,390 respectively.

Figure 10: Loss of Net Present Value between hyperbolic and exponential discount functions for a 7.0% real discount rate

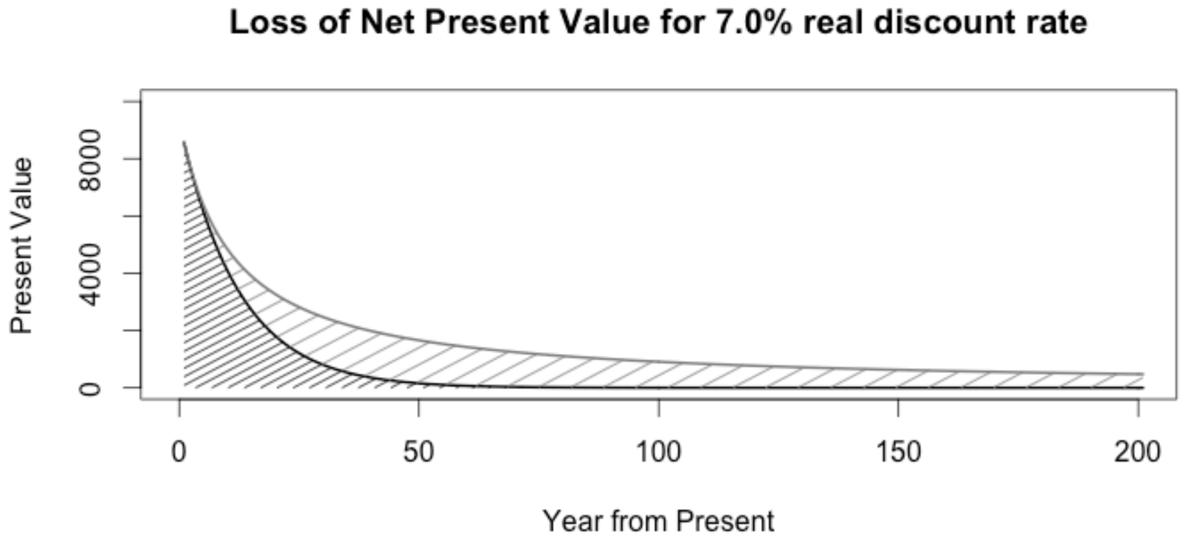


Figure 11: Loss of Net Present Value between hyperbolic and exponential discount functions for a 3.5% real discount rate

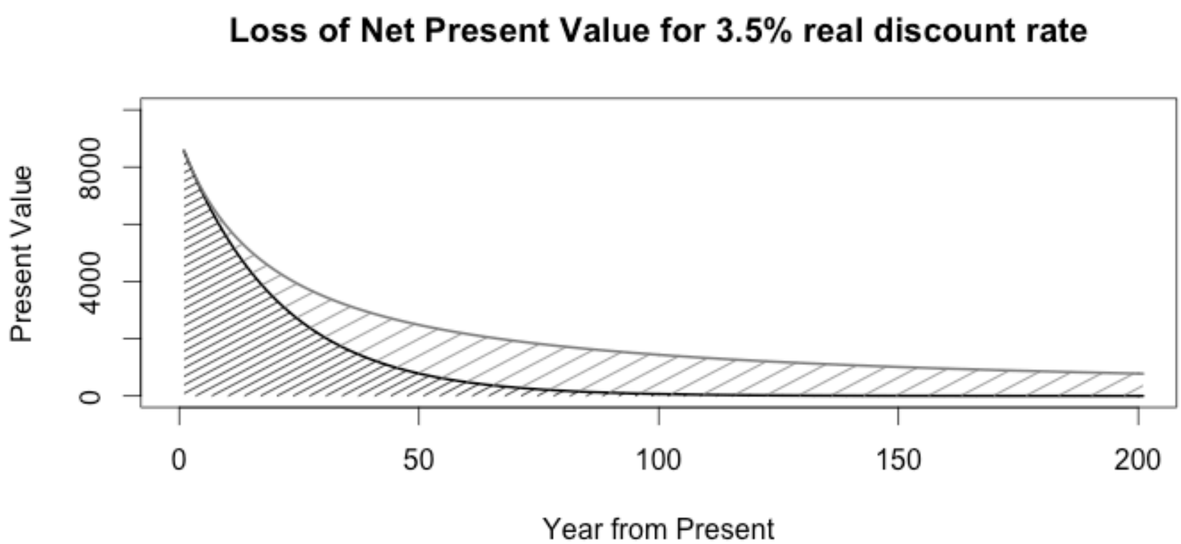


Figure 12: Loss of Net Present Value between hyperbolic and exponential discount functions for a 3.0% real discount rate

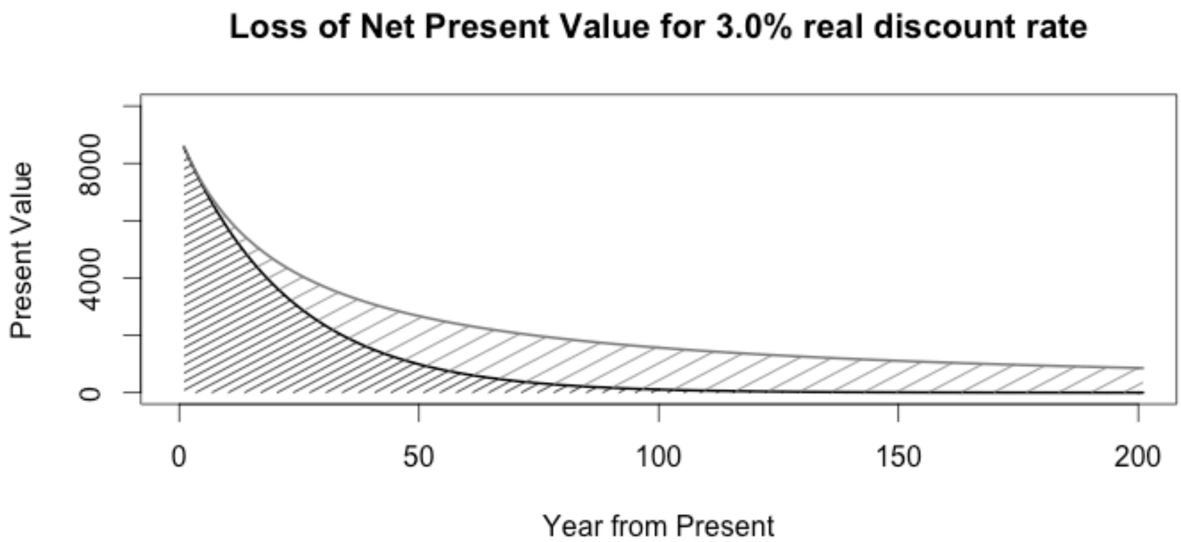
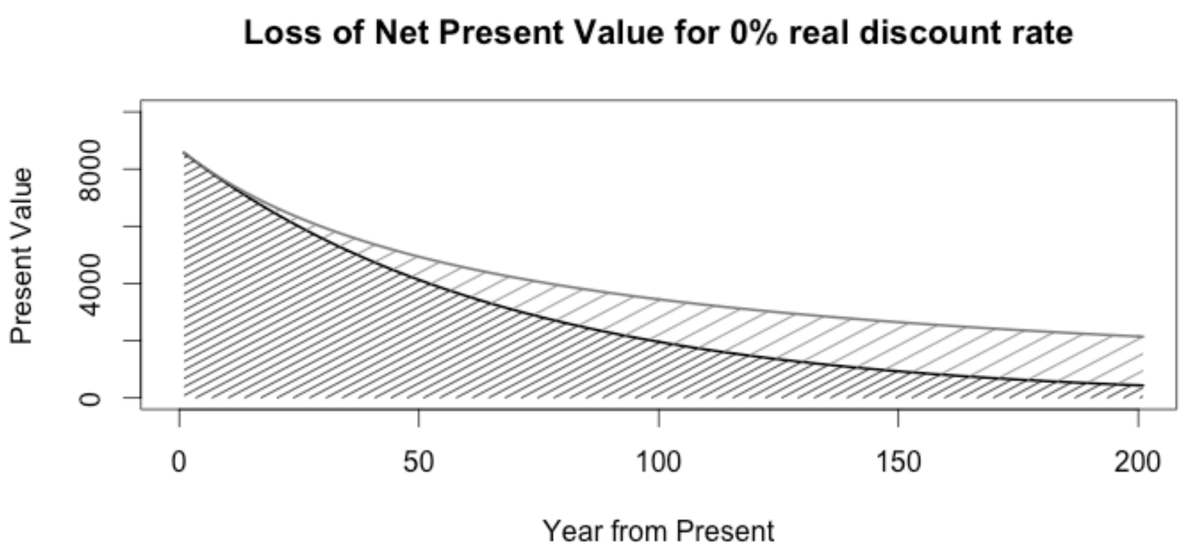


Figure 13: Loss of Net Present Value between hyperbolic and exponential discount functions for a 0% real discount rate



4.4 Statistical Analysis

4.4.1 Descriptive Statistics

In order to provide a more detailed understanding of both the present value and net present value at the years of interest for this investigation, descriptive statistics including the mean and standard deviation were calculated. Table 6 summarizes this information for the present value.

Table 6: Summary of mean and standard deviation of present values for all discounting scenarios at 20, 50, 100, and 200 years

Year		20	50	100	200
Exponential @ 7.0%	Mean	$1,675	$145	$2	$0
	Std. Dev.	$1,263	$109	$2	$0
Exponential @ 3.5%	Mean	$3,227	$747	$65	$0
	Std. Dev.	$2,433	$563	$49	$0
Exponential @ 3.0%	Mean	$3,551	$948	$105	$1
	Std. Dev.	$2,677	$715	$79	$1
Exponential @ 0%	Mean	$6,358	$4,068	$1,932	$436
	Std. Dev.	$4,793	$3,066	$1,457	$329
Hyperbolic @ 7.0%	Mean	$3,172	$1,631	$901	$476
	Std. Dev.	$2,391	$1,230	$680	$359
Hyperbolic @ 3.5%	Mean	$4,282	$2,447	$1,427	$778
	Std. Dev.	$3,228	$1,844	$1,076	$587
Hyperbolic @ 3.0%	Mean	$4,507	$2,635	$1,557	$856
	Std. Dev.	$3,398	$1,986	$1,174	$646
Hyperbolic @ 0%	Mean	$6,587	$4,893	$3,425	$2,141
	Std. Dev.	$4,966	$3,689	$2,582	$1,614

For a summary of the average net present value for all discounting scenarios at 20, 50, 100, and 200 years, see Table 5 in Section 4.3. The table below provides a summary of the standard deviations of the net present values for all discounting scenarios at 20, 50, 100, and 200 years.

Table 7: Standard Deviation of Net Present Values for all Exponential and Hyperbolic Discounting Scenarios calculated for 20-, 50-, 100-, and 200-year time horizons

YEAR	20	50	100	200
Exponential @ 7.0%	$67,544	$81,115	$82,378	$82,400
Exponential @ 3.5%	$86,903	$124,303	$134,580	$135,554
Exponential @ 3.0%	$90,425	$134,025	$148,148	$149,885
Exponential @ 0%	$117,284	$232,389	$339,708	$414,900
Hyperbolic @ 7.0%	$79,895	$129,820	$174,586	$222,961
Hyperbolic @ 3.5%	$94,351	$165,914	$235,119	$313,130
Hyperbolic @ 3.0%	$97,019	$173,322	$248,386	$333,883
Hyperbolic @ 0%	$118,623	$245,910	$398,854	$600,638

4.4.2 Statistical Testing

Statistical testing was performed to evaluate whether or not a statistically significant difference existed between the average net present values of the exponentially and hyperbolically discounted scenarios for each discount rate at 20, 50, 100, and 200 years. Due to a small sample size, a large degree of uncertainty was present, leading to a failure to reject the null hypothesis that there was no difference in the average net present value for most scenarios. A student's t-test was performed for at both the 95%, 90%, and 80% confidence levels. The results are summarized in Tables 7 through 10. At 20 and 50 years, there was no significant difference between exponentially and hyperbolically calculated average net present values at any tested level of confidence. At 100 years, a significant difference between exponentially and hyperbolically calculated average net present values existed at the 80% confidence level for the 7.0% and 3.5% discount rates. At 200 years, a significant difference between exponentially and hyperbolically calculate average net present values existed at the 80% and 90% confidence level for the 7.0%, 3.5%, and 3.0% discount rates.

Table 8: Results of student's unpaired t-test for the comparison of exponentially and hyperbolically discounted Net Present Values at year 20

Discount Rate Year = 20	p-value	Significant at 95% (alpha=0.05)	Significant at 90% (alpha=0.1)	Significant at 80% (alpha=0.2)
7.0%	0.6648	No	No	No
3.5%	0.8307	No	No	No
3.0%	0.8547	No	No	No
0%	0.9764	No	No	No

Table 9: Results of student's unpaired t-test for the comparison of exponentially and hyperbolically discounted Net Present Values at year 50

Discount Rate Year = 50	p-value	Significant at 95% (alpha=0.05)	Significant at 90% (alpha=0.1)	Significant at 80% (alpha=0.2)
7.0%	0.2561	No	No	No
3.5%	0.4648	No	No	No
3.0%	0.5126	No	No	No
0%	0.8830	No	No	No

Table 10: Results of student's unpaired t-test for the comparison of exponentially and hyperbolically discounted Net Present Values at year 100

Discount Rate Year = 100	p-value	Significant at 95% (alpha=0.05)	Significant at 90% (alpha=0.1)	Significant at 80% (alpha=0.2)
7.0%	0.1035	No	No	Yes
3.5%	0.1910	No	No	Yes
3.0%	0.2191	No	No	No
0%	0.6785	No	No	No

Table 11: Results of student's unpaired t-test for the comparison of exponentially and hyperbolically discounted Net Present Values at year 200

Discount Rate Year = 200	p-value	Significant at 95% (alpha=0.05)	Significant at 90% (alpha=0.1)	Significant at 80% (alpha=0.2)
7.0%	0.0541	No	Yes	Yes
3.5%	0.0808	No	Yes	Yes
3.0%	0.0895	No	Yes	Yes
0%	0.3579	No	No	No

Chapter 5: Discussion

This section contextualizes the results from Chapter 4. Threats to validity are explained and the numeric outcomes are discussed with respect to underlying economic theory. Uncertainties and implications for planning are also discussed.

5.1 Threats to Validity

5.1.1 Data Acquisition and Bias

One of the most difficult aspects of this study was obtaining appropriate data. When querying the University of Washington library database, a significant issue presented itself: using only a few keywords, searches returned peer-reviewed articles that focused on either ecological functions of coastal wetlands, but not economic valuations, or valuations for ecosystems that were not limited to coastal wetlands. However, when additional keywords were used in an attempt to isolate only coastal wetland valuations, few, if any, articles were returned. There appeared to be a maximum threshold for the number of search keywords that could be used in order to have any articles returned, and as such, the search became prohibitively specific as the number of keywords increased.

In order to isolate coastal wetland ecosystem service valuations using the library database, articles returned using more general search criteria were individually examined to determine whether they contained appropriate valuation data for the ecosystem of focus. This required a substantial amount of vetting, and uncovered some issues regarding the format of data reported. Some of the more broad valuations of ecosystem services across a large geographic area (for example, a state) did not always break down economic valuations for particular ecosystems, or broke down ecosystems more broadly, such as the generic term "wetlands" instead of specifying coastal or riverine wetland. In some studies, terms like "saltwater marsh" or "saltwater estuary" were used to described an particular ecosystem that was functionally similar to a coastal wetland, but did not explicitly use the term coastal wetland.

Perhaps one of the most frustrating aspects of data acquisition was the conversion of information presented into a usable form. In most studies, values were presented as a function of area, either as a per acre or hectare value or with a total value plus explicit information regarding the spatial boundaries of the ecosystem in question. However, some studies, especially those that used a household based willingness to pay or willingness to avoid valuation survey to estimate the value of coastal wetlands, reported values on a per household basis, making it difficult to compare these values to other studies unless both the number of households in the study area and the total area of wetlands for the project in question were explicitly indicated.

5.1.2 Widespread use of the Benefit Transfer Method for valuation studies

A close examination of ecosystem service valuation studies revealed a potential issue that called into question the accuracy of published valuation estimates: very few studies attempted to generate their own estimates of individual service values, opting instead to rely on other published values to generate estimates. As described in Section 2.2, this process is known as the benefit transfer method.

This method offers several advantages, including reducing the time and effort needed to conduct ecosystem service valuations, as well as research costs. In the event that a rapid turnaround is required for a particular valuation (challenging a permit approval, etc.), utilizing published values from other studies can be advantageous as it allows for the defensible estimation of an ecosystem's value. In general, this practice leads to a appropriate initial estimation.

However, there are a number of drawbacks of emphasizing this method. First and foremost, it relies on the assumption that other published values are correct. This in turn creates its own separate issue: if ecosystem service valuations are repeatedly estimated using existing literature, this limits the possibility of new data being added to the pool of peer-reviewed literature. Many of the initial estimates used are over a decade old, and in some cases, dating back nearly twenty years. For example, studies that relied heavily on Costanza *et al*'s 1997 paper, which brought ecosystem service valuations to the forefront of academic literature, may have been published several years later, and then cited as estimates in more recent academic articles. These more modern articles are therefore, at best, using inflation-adjusted estimates of values from the 1990's. This issue is exacerbated by the fact that continued scientific discovery and investigation into ecosystems and their services has revealed greater intricacies and complexities within the system, including the identification of additional services and functions that were previously unknown or not well understood. Therefore, using old estimates, even after adjusting for inflation, will lead researchers to underestimate service valuations for the ecosystem as a whole.

5.1.3 Statistical Analysis

While the descriptive statistics and statistical testing described in Section 4.4 provides a general understanding of the data, this information should not be over-generalized. Given that the valuation samples consisted of only eight data points, it would be inappropriate to place a high degree of confidence in the conclusions for statistical significance of the difference between the average net present values associated with the exponentially and hyperbolically generated projections for the 7.0% and 3.5% discount rate for year 100 and the 7.0%, 3.5%, and 3.0% discount rate for year 200. It is unlikely that the sample exhibited a Normal distribution, or that it was even representative of the overall population of coastal wetland ecosystem service valuations. Additionally, the large range of values for the original data resulted in relatively high standard deviations for the projected samples at all time periods of evaluation, leading to a substantial amount of uncertainty regarding accuracy of the population means. This subsequently influenced the statistical testing and the failure to conclude that there was a significant difference in the average net present value for the exponentially and hyperbolically projected samples for the majority of years and discount rates of interest, even at the 80% confidence level.

5.1.4 External Validity

Despite minimal confidence in the accuracy of the statistical testing for this study, the general trends displayed by the results should hold true for similar studies due to the fact that discounting is simply a mathematical transformation. A greater degree of confidence in the results would likely occur if more data were collected for a future study of valuations for coastal wetland ecosystem services. At the very least, this current study provides some guidance on the impact of discount rate and function selection on the overall per acre value of all coastal wetland ecosystem services. However, caution should be exercised when comparing these results across other ecosystems, as functional differences in services may obscure value trends. A similar methodology applied to another ecosystem, such as a forest or grassland, should exhibit similar trends when compared in insolation, but these trends may not hold true when comparing a coastal wetland to a forest.

5.2 A Return to Underlying Economic Theory

5.2.1 Increasing versus Diminishing Returns

Returning to the underlying economic theory, one must again consider the importance of the nature of the good in question and its tendency to exhibit increasing or decreasing returns. Economist Alfred Marshall summarizes this concept well:

> "Taking account of the fact that an increasing density of population generally brings with it access to new social enjoyments we may give a rather broader scope to this statement and say: An increase of population accompanied by an equal increase in the material sources of enjoyment and aids to production is likely to lead to a more than proportionate increase in the aggregate income of enjoyment of all kinds..." (Marshall, 1890: 31)

In the classical sense, increasing returns have often been used to explain the observed increase in outputs in excess of an expected proportionate increase based on an increase in inputs. As discussed in Section 2.5.2, Adam Smith's initial description of increasing returns was based on observations of the more than proportionate increase in production resulting from the division of labor during industrialization. As the field of economics has evolved over several hundred years, the idea of increasing returns has moved beyond the restrictive bounds of the division of labor, and refers to "…something much broader in scope than that splitting up of occupations and development of specialized crafts that Adam Smith mostly had in mind" (Young, 1928: 35). The general field of economics has grown and developed over time, leading to specific disciplines dealing with labor markets, international trade, and transaction costs. By the 1950's, biology and environmental issues were being viewed through an economic lens, with scholars noting the similarities between speciation and the division of labor and the practicality of examining natural phenomena using adaptations of common economic principles (Houthakker, 1956: 65-67). Just as the concept of increasing returns spread specifically from the division of labor to more general inputs in production functions as well as technological advances, this concept is readily transmitted to the field of environmental economics. Nicholas Kaldor noted the importance of elasticity as a requirement for the presence of increasing returns, as well as the ability of an economy to absorb excess "stocks" (resulting from increasing returns) and to accommodate "flows" of capital through various markets and sectors (Kaldor, 1972: 95-97). Resilient ecosystems display similar characteristics, as shown through their ability to cycle nutrients and adapt to changing conditions. Population dynamics of particular species change over time in response to their environment, absorbing additional resource stocks by reproducing and expanding the population while resources are readily accessible. Ecosystems can also accommodate flows of energy, facilitating its transformation from one form into another.

As discussed in Section 2.5.2, ecological systems are fundamentally different from other goods, like gray infrastructure. When considering whether or not a particular good (or service in this case) is subject to diminishing returns or enjoys increasing returns, the nature of the asset is critical. This importance cannot be understated. Consider the difference between a wastewater treatment facility and a wetland. Though they provide similar functions, each operates under a different set of rules, not only with regard to their physical aspects and constraints, but in their behavior as economic goods as well. One key difference is agglomeration: wetlands possess the ability to agglomerate and realize the benefits associated with an accumulation of natural capital, while wastewater treatment plants do not. In addition to the physical differences between "gray" and "green" infrastructure, the time horizon on which each is typically considered can impact the extent of this agglomeration. In his discussion of the necessary requirements for increasing returns to manifest, Allyn Young noted that "…accumulation of the necessary capital takes time, even though the process of accumulation is largely one of turning part of an increasing product into forms which will serve in securing a further increase of product." (Young, 1928: 39). Some natural processes that allow for the accumulation of natural capital are slow, taking hundreds of years to fully manifest. Therefore, if the timeframe of interest is limited to that of typical "gray" infrastructure, the agglomeration that begets increasing returns may not adequately present itself within the period of observation, leading to the false conclusion that the particular "green" infrastructure is subject to diminishing returns and diseconomies of scale.

5.2.2 Problems with Benefit Cost Analysis Presumptions

Central to the principles of benefit cost analysis is the concept of Pareto efficiency: that all possible trades or transactions which benefit at least one party while not causing another party to be made worse off have been exhausted (i.e. the Pareto optimality criterion).

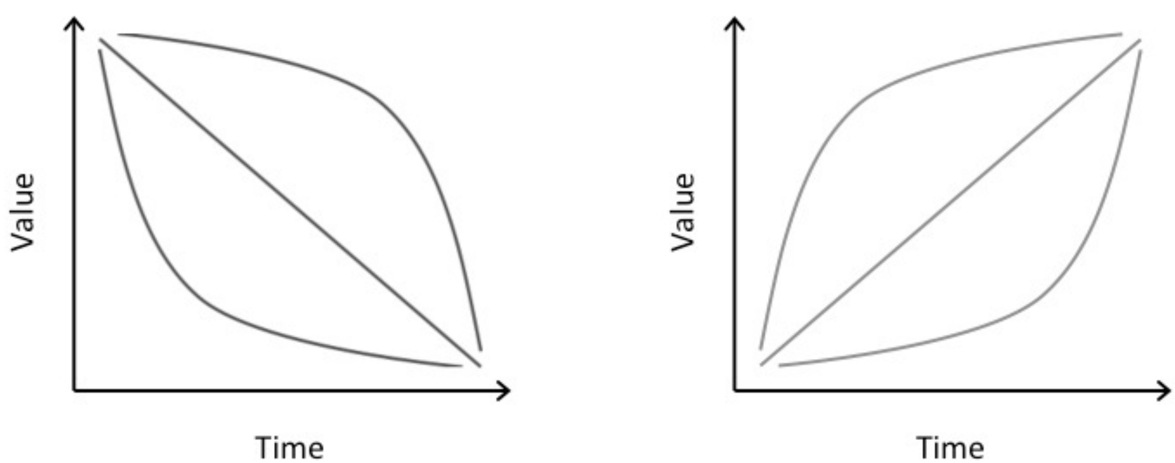
While this may hold true for transactions involving only a small number of parties, the Pareto assumption fails when considering projects that affect exceedingly large numbers of individuals or firms, especially on a long time horizon. Arrow noted the failure of the Pareto criterion in his impossibility theorem, indicating that a rank ordering of individual preferences cannot necessarily be translated into a singular social preference while also adhering to several criteria, including Pareto efficiency and the presence of a non-dictatorship (Arrow, 1950). Given the vast number of individuals whose preferences would need to be taken into account, including individuals in future generations, it would be improper to assume that any economic outcome would in fact satisfy Pareto efficiency assumption of benefit cost analysis. From an economic perspective, any non-sustainable consumption of ecosystem services, ranging from over use and its subsequent degradation to the complete removal or destruction of the service, might increase utility in the short term, but would substantially reduce utility in the long term. Abusing coastal wetland ecosystem services in the current generation, such as wastewater treatment, or the destruction of coastal wetlands in favor of development, reduces the availability of these wetlands and their services for future generations, affecting all future individuals who would presumably favor the benefits of the ecosystem, including protection from storm surge and sea level rise, as well as the preservation of biodiversity. By failing to account for the preferences of future generations, the underlying assumption of Pareto efficiency fails when examining ecosystem services from a benefit cost analysis lens.

5.2.3 Using negative real discount rates

In order to better account for increased scarcity and increasing relative value of ecosystems and their services in the future, it may be necessary to radically rethink the way in which we handle discounting. In an effort to better represent the presence of increasing returns in ecological systems, negative real discount rates could be used to represent this appreciation in value. If both exponential and hyperbolic discounting with positive real rates are emblematic of diminishing returns, why should either method be applied to the net present valuation of ecosystem services on a long time horizon? Though hyperbolic discount does retain higher present values in the far future, it still represents the assumption of diminishing returns, and therefore its application is fundamentally flawed.

The hyperbolic function is an improvement over the exponential function for positive real discounting, but it still lies on the left side of Figure 3. Transitioning to the right side of Figure 3 requires popular economics to effectively flip its interpretation of the time value of money issue. It may also lead to inconsistencies regarding rationality. If a negative discount rate is used to convert future ecosystem service benefits into present values, those present values will increase over time. Logically, this makes sense given an argument of increasing returns. A rational actor would see increasing value in the future, and choose to not consume until the value reaches its maximum. However, unless a function is designated for this calculation that reaches a maximum point, no consumption will occur because under the exponential and hyperbolic discounting functions, a negative rate will cause a continual increase over time. Practically speaking, this would mean that the rational actor would forsake all consumption. In terms of ecosystem services, this would mean that all benefits from an ecosystem would be conserved in their entirety, including consumables that humans rely on such as food. In order to survive, individuals would be forced to behave "irrationally" by choosing to consume ecosystem services in every time period instead.

Figure 3 (revisited): Conceptual Representation of Diminishing Returns (left) and Increasing Returns (right) shown as a function of value over time



5.3 Uncertainty and Implications for Planning

5.3.1 Market Failures Revisited: Transaction Costs

Returning to the concept of transaction costs and their impact on the efficiency of market allocations, it may be prudent to reconsider the use of ecosystem services valuations as a policy or economic decision making tool. Two main components of Coase's work on transaction costs emerge as key issues that must be addressed when considering the appropriateness using ecosystem service valuations for policy decisions: the individual, or marginal, costs associated with conducting a valuation study and the cumulative cost of conducting and implementing valuations.

The individual transaction costs associated with conducting ecosystem service valuations are numerous, mainly arising from the complexity of attempting to establish an efficient market that accurately represents the true value of the particular service in question. One particular barrier to the efficient market allocation and price signaling is the lack of access to complete information regarding individual preferences, especially in the case of future generations. Additionally, the sheer number of individuals poses a problem: "…a large number of people are involved and in which therefore the costs of handling the problem through the market or the firm may be high" (Coase:1960: 18). This issue is further exacerbated by the fact that when a far-future time horizon is considered, the number of individuals whose preferences would need to be evaluated is infinite.

From an efficiency standpoint, expending the time and energy to conduct ecosystem service valuations for every conservation or development decision attempt to understand the estimated value of particular ecosystem seems foolish:

> "It would clearly be desirable if the only actions performed were those in which what was gained was worth more than what was lost. But in choosing between social arrangements within the context of which individual decisions are made, we have to bear in mind that a change in the existing system which will lead to an improvement in some decisions may well lead to a worsening of others. Furthermore we have to take into account the costs involved in operating the various social arrangements (whether it be the working of a market or of a governmental department), as well as the costs involved in moving to a new system. In devising and choosing between social arrangements *we should have regard for the total effect*." (Coase, 1960: 44, emphasis added)

Ecosystem service valuations can be expensive to conduct properly. However, on the margin, they are assumed to cost less than the administration of a regulatory framework providing environmental protection aimed as preserving ecosystem services. Government intervention in the form of a regulatory framework is perceived as being quite costly, requiring not only investments for documentation and enforcement, but litigation as well. Stemming from the idea of the government regulation of nuisances, it seems only logical to apply the same regulatory framework to the potential nuisance of the loss of ecosystem services to both current and future generations instead of addressing each individual nuisance occurrence through market of legal rights (Coase, 1960: 17-19).

Generally speaking, it is prudent to closely consider the explicit and implicit costs incurred when comparing the economic, market based framework of ecosystem services and a regulatory framework: "Satisfactory views on policy can only come from a patient study of how, in practice, the market, firms, and governments handle the problem of harmful effects" (Coase, 1960:18). In any case, the total social costs of either approach must be carefully evaluated and used as the basis for sound policy with regard to maintenance and preservation of ecosystem services.

5.3.2 Potential Implications of Undervaluing Ecosystems

The consequences of undervaluing ecosystem services are quite dire, especially within the context of a market-based framework for decision-making (Costanza *et al*, 2014: 154). Chapter 4 highlights some of the discrepancies between valuations resulting from three sources: the discount rate, the discount function, and the time horizon. The standard approach to discounting in economic literature is through the use of an exponential function. However, this has been demonstrated to substantially reduce the far future values of coastal wetland ecosystem services, especially when using a higher discount rate. Substantially undervalued ecosystems may be subject to developmental pressure in the absence of legal protections, leading to degradation or total loss of their services. While the relative value of the remaining functional ecosystem may increase, the inherent flaws in the arbitrary assignment of discount rates and time horizon for net present valuation will continue to result in further scarcity.

Loss of ecosystem services, especially those provided by coastal wetlands will have significant impacts on future mitigation strategies and costs, especially in the face of climate change, increasing storm intensity and surges, and sea level rise. Threats to biodiversity will reduce ecosystem resilience and promote further disparities with regards to interspecies equity. Overall, the undervaluing of ecosystem services will lead to continued environmental degradation, leaving future generations with limited ecological resources.

Chapter 6: Conclusion

This thesis set out to explore the impacts of discount function and rate selection on the net present valuation of coastal wetland ecosystem services. A review of relevant economic and ecological literature noted some of the inherent flaws of attempting to assign values to ecosystems and using said valuations for decision making in accordance with benefit cost analysis. Using peer-reviewed literature to compile data on previously conducted valuations, per acre dollar values were projected to 200 years using several discount rates for both exponential and hyperbolic discount functions. Substantial differences in value were found, resulting from not only the rate and function selection, but for the time horizon of valuation as well. This suggests that the somewhat arbitrary assignment of these three variables needs to be carefully reconsidered, especially when valuation studies are used in a decision making process, such as whether or not to develop an area or undertake a restoration project. Examining the results in a transaction cost context, it may be preferable to utilize regulatory frameworks to protect ecosystems and their services as opposed to a strictly economic valuation.

While this thesis sheds some light onto the subject of the inherent flaws of ecosystem service valuations, more research is needed. Specific avenues of continued investigation include how ecosystem service valuations are actually used in the context of policy decisions and the emergence of hyperbolic discounting as a popular function for present value calculations and what can be done to encourage its use for economic valuations. Other avenues of research include continued study of ecosystems to better define their functions and new empirical studies that undertake their own specific, contextual, and original valuations instead of relying heavily on the benefit transfer method.

The practical application of ecosystem service valuation should also be reconsidered. While there is no harm in using valuation estimates to gain a general understanding of how much an ecosystem might be worth, it is important to understand that the calculated estimates are likely to be a dramatic undervaluation of the true worth of the ecosystem, and that ecosystem service valuations should only be used for firm policy decisions when there is a high degree of confidence in their estimated values (Costanza *et al*, 2014: 153-157). A more appropriate way of addressing ecosystems and their value is to address the general goals that led to the initial determination to conduct a valuation study. If the valuation study is being used to argue for the protection of an ecosystem, it may be a better alternative to simply assign legal protections to the ecosystem through a regulatory framework, thus prohibiting its destruction or intentional degradation. If society is to appropriately consider the allocation of environmental resources, including ecosystem services, to future generations, it will be necessary to exercise normative goals to this end in the form of policy decisions. Substantial uncertainty in both the calculation of value of ecosystem services and the validity of applying such valuations to a decision based on benefit cost analysis may result in the continued loss of ecosystem services on a global scale.

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Appendix A

Camacho-Valdez, Vera, Arturo Ruiz-Luna, Andrea Ghermandi, Paulo A.L.D. Nunes. 2013. "Valuation of ecosystem services provided by coastal wetlands in northwest Mexico". *Ocean & Coastal Management* 78:1-11.

Total coastal wetland area: 55,637 hectares
Total coastal wetland area: 137,482 acres
Valuation: $1,000,000,000
Valuation per acre: $7,274
Dollar year = 2003

Liu, Shuang, Robert Costanza, Austin Troy, John D'aagostino, and Willam Mates. 2010. "Valuing New Jersey's Ecosystem Services and Natural Capital: A Spatially Explicit Benefit Transfer Approach". *Environmental Management* 45 (6): 1271-85.

Total coastal wetland area: 190,520 acres
Valuation maximum: $1,243,545,862
Valuation minimum: $1,168,014,271
Valuation per acre (maximum): $6,527
Valuation per acre (minimum): $6,131
Dollar year = 2004

Raheem, N., S. Colt, E. Fleishman, J. Talberth, P. Swedeen, K.J. Boyle, M. Rudd, R.D. Lopez, D. Crocker, D. Bohan, T. O'Higgins, C. Willer, and R.M. Boumans. 2012. "Application of non-market valuation to California's coastal policy decisions". *Marine Policy* 36(5): 1166-1171.

Total coastal wetland area: N/A
Valuation per acre(maximum): $3,923
Valuation per acre(minimum): $2,040
Dollar year: 2008

Petrolia, Daniel R., Matthew G. Interis, and Joonghyun Hwang. 2014. "America's Wetland? A National Survey of Willingness to Pay for Restoration of Louisiana's Coastal Wetlands". *Marine Resource Economics* 29(1): 17-37.

Total costal wetland area: 234,000
Total willingness to pay nationally for a restoration project over 50 years: $105,000,000,000
Willingness to pay per acre: $448,717
Willingness to pay per acre per year: $8,974
Dollar year = 2013

Petrolia, Daniel R. and Tae-Goun Kim. 2011. “Preventing land loss in coastal Louisiana: Estimates of WTP and WTA”. *Journal of Environmental Management* 92(3): 859-865.

Total coastal wetland area: 700 square miles
Total coastal wetland area: 448,000 acres
Total number of tax returns (households): 2,146,273
Willingness to pay per household: $822
Total willingness to pay: $1,764,236,406
Willingness to accept compensation per household: $4,382
Total willingness to accept compensation: $9,404,968,286
Willingness to pay per acre: $3,938
Willingness to avoid per acre: $20,993
Dollar year: 2009

Appendix B

The full R script used to code for all calculations and plots is as follows:

```
###General
options(scipen=10)
data <- read.csv("data.csv")
data

###Creating matricies and variables for data
num.years <- 201
scen1 <- 0.085
scen2 <- 0.05
scen3 <- 0.045
scen4 <- 0.015

##Exponential discounting at 7.0% (8.5% nominal)
#discounted valued to year 200
exp.scen1 <- matrix(nrow=length(data$adjval), ncol=num.years)
for (i in 1:length(data$adjval)){
  for (j in 1:num.years){
    exp.scen1[i,j] <- ((data[i,3])*(1/((1+scen1)^(j-1))))
  }
}
exp.scen1

avg.exp.scen1 <- rep(0, num.years)
for (j in 1:num.years){
  avg.exp.scen1[j] = mean(exp.scen1[1:8,j])
}
avg.exp.scen1

#effective zero value (year at which present value <1% of current value)
yrzero <- avg.exp.scen1[1]/100
yrzero.exp.scen1 <- 1
for (j in 1:num.years){
  if(yrzero < avg.exp.scen1[j]) yrzero.exp.scen1 <- j
}
yrzero.exp.scen1

#declines to <10% of original value
yr10 <- avg.exp.scen1[1]/10
yr10.exp.scen1 <- 1
for (j in 1:num.years){
  if(yr10 < avg.exp.scen1[j]) yr10.exp.scen1 <- j
}
yr10.exp.scen1

#net present value at year 200
npv200.exp.scen1 <- rep(0, length(data$adjval))
npv200.exp.scen1j <- 0
for (i in 1:length(npv200.exp.scen1)){
  for (j in 1:num.years){
    npv200.exp.scen1j <- (npv200.exp.scen1j + exp.scen1[i,j])
  }
  npv200.exp.scen1[i] <- npv200.exp.scen1j
```

```
  npv200.exp.scen1j <- 0
}
npv200.exp.scen1

#NPV at year 100
npv100.exp.scen1 <- rep(0, length(data$adjval))
npv100.exp.scen1j <- 0
for (i in 1:length(npv100.exp.scen1)){
  for (j in 1:101){
    npv100.exp.scen1j <- (npv100.exp.scen1j + exp.scen1[i,j])
  }
  npv100.exp.scen1[i] <- npv100.exp.scen1j
  npv100.exp.scen1j <- 0
}
npv100.exp.scen1

#NPV at year 50
npv50.exp.scen1 <- rep(0, length(data$adjval))
npv50.exp.scen1j <- 0
for (i in 1:length(npv50.exp.scen1)){
  for (j in 1:51){
    npv50.exp.scen1j <- (npv50.exp.scen1j + exp.scen1[i,j])
  }
  npv50.exp.scen1[i] <- npv50.exp.scen1j
  npv50.exp.scen1j <- 0
}
npv50.exp.scen1

#NPV at year 20
npv20.exp.scen1 <- rep(0, length(data$adjval))
npv20.exp.scen1j <- 0
for (i in 1:length(npv20.exp.scen1)){
  for (j in 1:21){
    npv20.exp.scen1j <- (npv20.exp.scen1j + exp.scen1[i,j])
  }
  npv20.exp.scen1[i] <- npv20.exp.scen1j
  npv20.exp.scen1j <- 0
}
npv20.exp.scen1



##Exponential discounting at 3.5% (5.0% nominal)
#discounted valued to year 200
exp.scen2 <- matrix(nrow=length(data$adjval), ncol=num.years)
for (i in 1:length(data$adjval)){
  for (j in 1:num.years){
    exp.scen2[i,j] <- ((data[i,3])*(1/((1+scen2)^(j-1))))
  }
}
exp.scen2

avg.exp.scen2 <- rep(0, num.years)
for (j in 1:num.years){
  avg.exp.scen2[j] = mean(exp.scen2[1:8,j])
}
avg.exp.scen2
```

```
#effective zero value (year at which present value <1% of current value)
yrzero <- avg.exp.scen2[1]/100
yrzero.exp.scen2 <- 1
for (j in 1:num.years){
  if(yrzero < avg.exp.scen2[j]) yrzero.exp.scen2 <- j
}
yrzero.exp.scen2

#declines to <10% of original value
yr10 <- avg.exp.scen2[1]/10
yr10.exp.scen2 <- 1
for (j in 1:num.years){
  if(yr10 < avg.exp.scen2[j]) yr10.exp.scen2 <- j
}
yr10.exp.scen2


#net present value at year 200
npv200.exp.scen2 <- rep(0, length(data$adjval))
npv200.exp.scen2j <- 0
for (i in 1:length(npv200.exp.scen2)){
  for (j in 1:num.years){
    npv200.exp.scen2j <- (npv200.exp.scen2j + exp.scen2[i,j])
  }
  npv200.exp.scen2[i] <- npv200.exp.scen2j
  npv200.exp.scen2j <- 0
}
npv200.exp.scen2

#NPV at year 100
npv100.exp.scen2 <- rep(0, length(data$adjval))
npv100.exp.scen2j <- 0
for (i in 1:length(npv100.exp.scen2)){
  for (j in 1:101){
    npv100.exp.scen2j <- (npv100.exp.scen2j + exp.scen2[i,j])
  }
  npv100.exp.scen2[i] <- npv100.exp.scen2j
  npv100.exp.scen2j <- 0
}
npv100.exp.scen2

#NPV at year 50
npv50.exp.scen2 <- rep(0, length(data$adjval))
npv50.exp.scen2j <- 0
for (i in 1:length(npv50.exp.scen2)){
  for (j in 1:51){
    npv50.exp.scen2j <- (npv50.exp.scen2j + exp.scen2[i,j])
  }
  npv50.exp.scen2[i] <- npv50.exp.scen2j
  npv50.exp.scen2j <- 0
}
npv50.exp.scen2

#NPV at year 20
npv20.exp.scen2 <- rep(0, length(data$adjval))
npv20.exp.scen2j <- 0
for (i in 1:length(npv20.exp.scen2)){
  for (j in 1:21){
```

```
    npv20.exp.scen2j <- (npv20.exp.scen2j + exp.scen2[i,j])
  }
  npv20.exp.scen2[i] <- npv20.exp.scen2j
  npv20.exp.scen2j <- 0
}
npv20.exp.scen2



##Exponential discounting at 3.0% (4.5% nominal)
#discounted valued to year 200
exp.scen3 <- matrix(nrow=length(data$adjval), ncol=num.years)
for (i in 1:length(data$adjval)){
  for (j in 1:num.years){
    exp.scen3[i,j] <- ((data[i,3])*(1/((1+scen3)^(j-1))))
  }
}
exp.scen3

avg.exp.scen3 <- rep(0, num.years)
for (j in 1:num.years){
  avg.exp.scen3[j] = mean(exp.scen3[1:8,j])
}
avg.exp.scen3

#effective zero value (year at which present value <1% of current value)
yrzero <- avg.exp.scen3[1]/100
yrzero.exp.scen3 <- 1
for (j in 1:num.years){
  if(yrzero < avg.exp.scen3[j]) yrzero.exp.scen3 <- j
}
yrzero.exp.scen3

#declines to <10% of original value
yr10 <- avg.exp.scen3[1]/10
yr10.exp.scen3 <- 1
for (j in 1:num.years){
  if(yr10 < avg.exp.scen3[j]) yr10.exp.scen3 <- j
}
yr10.exp.scen3

#net present value at year 200
npv200.exp.scen3 <- rep(0, length(data$adjval))
npv200.exp.scen3j <- 0
for (i in 1:length(npv200.exp.scen3)){
  for (j in 1:num.years){
    npv200.exp.scen3j <- (npv200.exp.scen3j + exp.scen3[i,j])
  }
  npv200.exp.scen3[i] <- npv200.exp.scen3j
  npv200.exp.scen3j <- 0
}
npv200.exp.scen3

#NPV at year 100
npv100.exp.scen3 <- rep(0, length(data$adjval))
npv100.exp.scen3j <- 0
for (i in 1:length(npv100.exp.scen3)){
  for (j in 1:101){
```

```
    npv100.exp.scen3j <- (npv100.exp.scen3j + exp.scen3[i,j])
  }
  npv100.exp.scen3[i] <- npv100.exp.scen3j
  npv100.exp.scen3j <- 0
}
npv100.exp.scen3

#NPV at year 50
npv50.exp.scen3 <- rep(0, length(data$adjval))
npv50.exp.scen3j <- 0
for (i in 1:length(npv50.exp.scen3)){
  for (j in 1:51){
    npv50.exp.scen3j <- (npv50.exp.scen3j + exp.scen3[i,j])
  }
  npv50.exp.scen3[i] <- npv50.exp.scen3j
  npv50.exp.scen3j <- 0
}
npv50.exp.scen3

#NPV at year 20
npv20.exp.scen3 <- rep(0, length(data$adjval))
npv20.exp.scen3j <- 0
for (i in 1:length(npv20.exp.scen3)){
  for (j in 1:21){
    npv20.exp.scen3j <- (npv20.exp.scen3j + exp.scen3[i,j])
  }
  npv20.exp.scen3[i] <- npv20.exp.scen3j
  npv20.exp.scen3j <- 0
}
npv20.exp.scen3



##Exponential discounting at 0% (1.5% nominal)
#discounted valued to year 200
exp.scen4 <- matrix(nrow=length(data$adjval), ncol=num.years)
for (i in 1:length(data$adjval)){
  for (j in 1:num.years){
    exp.scen4[i,j] <- ((data[i,3])*(1/((1+scen4)^(j-1))))
  }
}
exp.scen4

avg.exp.scen4 <- rep(0, num.years)
for (j in 1:num.years){
  avg.exp.scen4[j] = mean(exp.scen4[1:8,j])
}
avg.exp.scen4

#effective zero value (year at which present value <1% of current value)
yrzero <- avg.exp.scen4[1]/100
yrzero.exp.scen4 <- 1
for (j in 1:num.years){
  if(yrzero < avg.exp.scen4[j]) yrzero.exp.scen4 <- j
}
yrzero.exp.scen4

#declines to <10% of original value
```

```
yr10 <- avg.exp.scen4[1]/10
yr10.exp.scen4 <- 1
for (j in 1:num.years){
  if(yr10 < avg.exp.scen4[j]) yr10.exp.scen4 <- j
}
yr10.exp.scen4


#net present value at year 200
npv200.exp.scen4 <- rep(0, length(data$adjval))
npv200.exp.scen4j <- 0
for (i in 1:length(npv200.exp.scen4)){
  for (j in 1:num.years){
    npv200.exp.scen4j <- (npv200.exp.scen4j + exp.scen4[i,j])
  }
  npv200.exp.scen4[i] <- npv200.exp.scen4j
  npv200.exp.scen4j <- 0
}
npv200.exp.scen4

#NPV at year 100
npv100.exp.scen4 <- rep(0, length(data$adjval))
npv100.exp.scen4j <- 0
for (i in 1:length(npv100.exp.scen4)){
  for (j in 1:101){
    npv100.exp.scen4j <- (npv100.exp.scen4j + exp.scen4[i,j])
  }
  npv100.exp.scen4[i] <- npv100.exp.scen4j
  npv100.exp.scen4j <- 0
}
npv100.exp.scen4

#NPV at year 50
npv50.exp.scen4 <- rep(0, length(data$adjval))
npv50.exp.scen4j <- 0
for (i in 1:length(npv50.exp.scen4)){
  for (j in 1:51){
    npv50.exp.scen4j <- (npv50.exp.scen4j + exp.scen4[i,j])
  }
  npv50.exp.scen4[i] <- npv50.exp.scen4j
  npv50.exp.scen4j <- 0
}
npv50.exp.scen4

#NPV at year 20
npv20.exp.scen4 <- rep(0, length(data$adjval))
npv20.exp.scen4j <- 0
for (i in 1:length(npv20.exp.scen4)){
  for (j in 1:21){
    npv20.exp.scen4j <- (npv20.exp.scen4j + exp.scen4[i,j])
  }
  npv20.exp.scen4[i] <- npv20.exp.scen4j
  npv20.exp.scen4j <- 0
}
npv20.exp.scen4
```

```
##Hyperbolic discounting at 7.0% (8.5% nominal)
#discounted valued to year 200
hyp.scen1 <- matrix(nrow=length(data$adjval), ncol=num.years)
for (i in 1:length(data$adjval)){
  for (j in 1:num.years){
    hyp.scen1[i,j] <- ((data[i,3])*(1/((1+(scen1*(j-1))))))
  }
}
hyp.scen1

avg.hyp.scen1 <- rep(0, num.years)
for (j in 1:num.years){
  avg.hyp.scen1[j] = mean(hyp.scen1[1:8,j])
}
avg.hyp.scen1


#effective zero value (year at which present value <1% of current value)
yrzero <- avg.hyp.scen1[1]/100
yrzero.hyp.scen1 <- 1
for (j in 1:num.years){
  if(yrzero < avg.hyp.scen1[j]) yrzero.hyp.scen1 <- j
}
yrzero.hyp.scen1

#declines to <10% of original value
yr10 <- avg.hyp.scen1[1]/10
yr10.hyp.scen1 <- 1
for (j in 1:num.years){
  if(yr10 < avg.hyp.scen1[j]) yr10.hyp.scen1 <- j
}
yr10.hyp.scen1


#net present value at year 200
npv200.hyp.scen1 <- rep(0, length(data$adjval))
npv200.hyp.scen1j <- 0
for (i in 1:length(npv200.hyp.scen1)){
  for (j in 1:num.years){
    npv200.hyp.scen1j <- (npv200.hyp.scen1j + hyp.scen1[i,j])
  }
  npv200.hyp.scen1[i] <- npv200.hyp.scen1j
  npv200.hyp.scen1j <- 0
}
npv200.hyp.scen1

#NPV at year 100
npv100.hyp.scen1 <- rep(0, length(data$adjval))
npv100.hyp.scen1j <- 0
for (i in 1:length(npv100.hyp.scen1)){
  for (j in 1:101){
    npv100.hyp.scen1j <- (npv100.hyp.scen1j + hyp.scen1[i,j])
  }
  npv100.hyp.scen1[i] <- npv100.hyp.scen1j
  npv100.hyp.scen1j <- 0
}
```

```
npv100.hyp.scen1

#NPV at year 50
npv50.hyp.scen1 <- rep(0, length(data$adjval))
npv50.hyp.scen1j <- 0
for (i in 1:length(npv50.hyp.scen1)){
  for (j in 1:51){
    npv50.hyp.scen1j <- (npv50.hyp.scen1j + hyp.scen1[i,j])
  }
  npv50.hyp.scen1[i] <- npv50.hyp.scen1j
  npv50.hyp.scen1j <- 0
}
npv50.hyp.scen1

#NPV at year 20
npv20.hyp.scen1 <- rep(0, length(data$adjval))
npv20.hyp.scen1j <- 0
for (i in 1:length(npv20.hyp.scen1)){
  for (j in 1:21){
    npv20.hyp.scen1j <- (npv20.hyp.scen1j + hyp.scen1[i,j])
  }
  npv20.hyp.scen1[i] <- npv20.hyp.scen1j
  npv20.hyp.scen1j <- 0
}
npv20.hyp.scen1



##Hyperbolic discounting at 3.5% (5.0% nominal)
#discounted valued to year 200
hyp.scen2 <- matrix(nrow=length(data$adjval), ncol=num.years)
for (i in 1:length(data$adjval)){
  for (j in 1:num.years){
    hyp.scen2[i,j] <- ((data[i,3])*(1/((1+(scen2*(j-1))))))
  }
}
hyp.scen2

avg.hyp.scen2 <- rep(0, num.years)
for (j in 1:num.years){
  avg.hyp.scen2[j] = mean(hyp.scen2[1:8,j])
}
avg.hyp.scen2

#effective zero value (year at which present value <1% of current value)
yrzero <- avg.hyp.scen2[1]/100
yrzero.hyp.scen2 <- 1
for (j in 1:num.years){
  if(yrzero < avg.hyp.scen2[j]) yrzero.hyp.scen2 <- j
}
yrzero.hyp.scen2

#declines to <10% of original value
yr10 <- avg.hyp.scen2[1]/10
yr10.hyp.scen2 <- 1
for (j in 1:num.years){
  if(yr10 < avg.hyp.scen2[j]) yr10.hyp.scen2 <- j
```

```
}
yr10.hyp.scen2


#net present value at year 200
npv200.hyp.scen2 <- rep(0, length(data$adjval))
npv200.hyp.scen2j <- 0
for (i in 1:length(npv200.hyp.scen2)){
  for (j in 1:num.years){
    npv200.hyp.scen2j <- (npv200.hyp.scen2j + hyp.scen2[i,j])
  }
  npv200.hyp.scen2[i] <- npv200.hyp.scen2j
  npv200.hyp.scen2j <- 0
}
npv200.hyp.scen2

#NPV at year 100
npv100.hyp.scen2 <- rep(0, length(data$adjval))
npv100.hyp.scen2j <- 0
for (i in 1:length(npv100.hyp.scen2)){
  for (j in 1:101){
    npv100.hyp.scen2j <- (npv100.hyp.scen2j + hyp.scen2[i,j])
  }
  npv100.hyp.scen2[i] <- npv100.hyp.scen2j
  npv100.hyp.scen2j <- 0
}
npv100.hyp.scen2

#NPV at year 50
npv50.hyp.scen2 <- rep(0, length(data$adjval))
npv50.hyp.scen2j <- 0
for (i in 1:length(npv50.hyp.scen2)){
  for (j in 1:51){
    npv50.hyp.scen2j <- (npv50.hyp.scen2j + hyp.scen2[i,j])
  }
  npv50.hyp.scen2[i] <- npv50.hyp.scen2j
  npv50.hyp.scen2j <- 0
}
npv50.hyp.scen2

#NPV at year 20
npv20.hyp.scen2 <- rep(0, length(data$adjval))
npv20.hyp.scen2j <- 0
for (i in 1:length(npv20.hyp.scen2)){
  for (j in 1:21){
    npv20.hyp.scen2j <- (npv20.hyp.scen2j + hyp.scen2[i,j])
  }
  npv20.hyp.scen2[i] <- npv20.hyp.scen2j
  npv20.hyp.scen2j <- 0
}
npv20.hyp.scen2




##Hyperbolic discounting at 3.0% (4.5% nominal)
#discounted valued to year 200
hyp.scen3 <- matrix(nrow=length(data$adjval), ncol=num.years)
```

```
for (i in 1:length(data$adjval)){
  for (j in 1:num.years){
    hyp.scen3[i,j] <- ((data[i,3])*(1/((1+(scen3*(j-1))))))
  }
}
hyp.scen3

avg.hyp.scen3 <- rep(0, num.years)
for (j in 1:num.years){
  avg.hyp.scen3[j] = mean(hyp.scen3[1:8,j])
}
avg.hyp.scen3

#effective zero value (year at which present value <1% of current value)
yrzero <- avg.hyp.scen3[1]/100
yrzero.hyp.scen3 <- 1
for (j in 1:num.years){
  if(yrzero < avg.hyp.scen3[j]) yrzero.hyp.scen3 <- j
}
yrzero.hyp.scen3

#declines to <10% of original value
yr10 <- avg.hyp.scen3[1]/10
yr10.hyp.scen3 <- 1
for (j in 1:num.years){
  if(yr10 < avg.hyp.scen3[j]) yr10.hyp.scen3 <- j
}
yr10.hyp.scen3


#net present value at year 200
npv200.hyp.scen3 <- rep(0, length(data$adjval))
npv200.hyp.scen3j <- 0
for (i in 1:length(npv200.hyp.scen3)){
  for (j in 1:num.years){
    npv200.hyp.scen3j <- (npv200.hyp.scen3j + hyp.scen3[i,j])
  }
  npv200.hyp.scen3[i] <- npv200.hyp.scen3j
  npv200.hyp.scen3j <- 0
}
npv200.hyp.scen3

#NPV at year 100
npv100.hyp.scen3 <- rep(0, length(data$adjval))
npv100.hyp.scen3j <- 0
for (i in 1:length(npv100.hyp.scen3)){
  for (j in 1:101){
    npv100.hyp.scen3j <- (npv100.hyp.scen3j + hyp.scen3[i,j])
  }
  npv100.hyp.scen3[i] <- npv100.hyp.scen3j
  npv100.hyp.scen3j <- 0
}
npv100.hyp.scen3

#NPV at year 50
npv50.hyp.scen3 <- rep(0, length(data$adjval))
npv50.hyp.scen3j <- 0
for (i in 1:length(npv50.hyp.scen3)){
```

```
  for (j in 1:51){
    npv50.hyp.scen3j <- (npv50.hyp.scen3j + hyp.scen3[i,j])
  }
  npv50.hyp.scen3[i] <- npv50.hyp.scen3j
  npv50.hyp.scen3j <- 0
}
npv50.hyp.scen3

#NPV at year 20
npv20.hyp.scen3 <- rep(0, length(data$adjval))
npv20.hyp.scen3j <- 0
for (i in 1:length(npv20.hyp.scen3)){
  for (j in 1:21){
    npv20.hyp.scen3j <- (npv20.hyp.scen3j + hyp.scen3[i,j])
  }
  npv20.hyp.scen3[i] <- npv20.hyp.scen3j
  npv20.hyp.scen3j <- 0
}
npv20.hyp.scen3




##Hyperbolic discounting at 0% (1.5% nominal)
#discounted valued to year 200
hyp.scen4 <- matrix(nrow=length(data$adjval), ncol=num.years)
for (i in 1:length(data$adjval)){
  for (j in 1:num.years){
    hyp.scen4[i,j] <- ((data[i,3])*(1/((1+(scen4*(j-1))))))
  }
}
hyp.scen4

avg.hyp.scen4 <- rep(0, num.years)
for (j in 1:num.years){
  avg.hyp.scen4[j] = mean(hyp.scen4[1:8,j])
}
avg.hyp.scen4

#effective zero value (year at which present value <1% of current value)
yrzero <- avg.hyp.scen4[1]/100
yrzero.hyp.scen4 <- 1
for (j in 1:num.years){
  if(yrzero < avg.hyp.scen4[j]) yrzero.hyp.scen4 <- j
}
yrzero.hyp.scen4

#declines to <10% of original value
yr10 <- avg.hyp.scen4[1]/10
yr10.hyp.scen4 <- 1
for (j in 1:num.years){
  if(yr10 < avg.hyp.scen4[j]) yr10.hyp.scen4 <- j
}
yr10.hyp.scen4


#net present value at year 200
npv200.hyp.scen4 <- rep(0, length(data$adjval))
```

```
npv200.hyp.scen4j <- 0
for (i in 1:length(npv200.hyp.scen4)){
  for (j in 1:num.years){
    npv200.hyp.scen4j <- (npv200.hyp.scen4j + hyp.scen4[i,j])
  }
  npv200.hyp.scen4[i] <- npv200.hyp.scen4j
  npv200.hyp.scen4j <- 0
}
npv200.hyp.scen1

#NPV at year 100
npv100.hyp.scen4 <- rep(0, length(data$adjval))
npv100.hyp.scen4j <- 0
for (i in 1:length(npv100.hyp.scen4)){
  for (j in 1:101){
    npv100.hyp.scen4j <- (npv100.hyp.scen4j + hyp.scen4[i,j])
  }
  npv100.hyp.scen4[i] <- npv100.hyp.scen4j
  npv100.hyp.scen4j <- 0
}
npv100.hyp.scen4

#NPV at year 50
npv50.hyp.scen4 <- rep(0, length(data$adjval))
npv50.hyp.scen4j <- 0
for (i in 1:length(npv50.hyp.scen4)){
  for (j in 1:51){
    npv50.hyp.scen4j <- (npv50.hyp.scen4j + hyp.scen4[i,j])
  }
  npv50.hyp.scen4[i] <- npv50.hyp.scen4j
  npv50.hyp.scen4j <- 0
}
npv50.hyp.scen4

#NPV at year 20
npv20.hyp.scen4 <- rep(0, length(data$adjval))
npv20.hyp.scen4j <- 0
for (i in 1:length(npv20.hyp.scen4)){
  for (j in 1:21){
    npv20.hyp.scen4j <- (npv20.hyp.scen4j + hyp.scen4[i,j])
  }
  npv20.hyp.scen4[i] <- npv20.hyp.scen4j
  npv20.hyp.scen4j <- 0
}
npv20.hyp.scen4




###maximum difference between average exp and hyp yearly PV's for each rate

##7.0%
max.diff.scen1 <- 0
yr.max.diff.scen1 <- 0
for (i in 1:num.years){
  if((avg.hyp.scen1[i]-avg.exp.scen1[i]) > max.diff.scen1)
    yr.max.diff.scen1 <- i-1
```

```
  if((avg.hyp.scen1[i]-avg.exp.scen1[i]) > max.diff.scen1)
    max.diff.scen1 <- (avg.hyp.scen1[i] - avg.exp.scen1[i])
}
max.diff.scen1
yr.max.diff.scen1

##3.5%
max.diff.scen2 <- 0
yr.max.diff.scen2 <- 0
for (i in 1:num.years){
  if((avg.hyp.scen2[i]-avg.exp.scen2[i]) > max.diff.scen2)
    yr.max.diff.scen2 <- i-1
  if((avg.hyp.scen2[i]-avg.exp.scen2[i]) > max.diff.scen2)
    max.diff.scen2 <- (avg.hyp.scen2[i] - avg.exp.scen2[i])
}
max.diff.scen2
yr.max.diff.scen2

##3.0%
max.diff.scen3 <- 0
yr.max.diff.scen3 <- 0
for (i in 1:num.years){
  if((avg.hyp.scen3[i]-avg.exp.scen3[i]) > max.diff.scen1)
    yr.max.diff.scen3 <- i-1
  if((avg.hyp.scen3[i]-avg.exp.scen3[i]) > max.diff.scen1)
    max.diff.scen3 <- (avg.hyp.scen3[i] - avg.exp.scen3[i])
}
max.diff.scen3
yr.max.diff.scen3

##0%
max.diff.scen4 <- 0
yr.max.diff.scen4 <- 0
for (i in 1:num.years){
  if((avg.hyp.scen4[i]-avg.exp.scen1[i]) > max.diff.scen4)
    yr.max.diff.scen4 <- i-1
  if((avg.hyp.scen4[i]-avg.exp.scen1[i]) > max.diff.scen4)
    max.diff.scen4 <- (avg.hyp.scen4[i] - avg.exp.scen4[i])
}
max.diff.scen4
yr.max.diff.scen4



###Statistical analysis

##Descriptive statistics
#PV at year 20
avg.exp.scen1[21]
sd(exp.scen1[,21])
avg.exp.scen2[21]
sd(exp.scen2[,21])
avg.exp.scen3[21]
sd(exp.scen3[,21])
avg.exp.scen4[21]
sd(exp.scen4[,21])
avg.hyp.scen1[21]
sd(hyp.scen1[,21])
```

```
avg.hyp.scen2[21]
sd(hyp.scen2[,21])
avg.hyp.scen3[21]
sd(hyp.scen3[,21])
avg.hyp.scen4[21]
sd(hyp.scen4[,21])

#PV at year 50
avg.exp.scen1[51]
sd(exp.scen1[,51])
avg.exp.scen2[51]
sd(exp.scen2[,51])
avg.exp.scen3[51]
sd(exp.scen3[,51])
avg.exp.scen4[51]
sd(exp.scen4[,51])
avg.hyp.scen1[51]
sd(hyp.scen1[,51])
avg.hyp.scen2[51]
sd(hyp.scen2[,51])
avg.hyp.scen3[51]
sd(hyp.scen3[,51])
avg.hyp.scen4[51]
sd(hyp.scen4[,51])

#PV at year 100
avg.exp.scen1[101]
sd(exp.scen1[,101])
avg.exp.scen2[101]
sd(exp.scen2[,101])
avg.exp.scen3[101]
sd(exp.scen3[,101])
avg.exp.scen4[101]
sd(exp.scen4[,101])
avg.hyp.scen1[101]
sd(hyp.scen1[,101])
avg.hyp.scen2[101]
sd(hyp.scen2[,101])
avg.hyp.scen3[101]
sd(hyp.scen3[,101])
avg.hyp.scen4[101]
sd(hyp.scen4[,101])

#PV at year 200
avg.exp.scen1[201]
sd(exp.scen1[,201])
avg.exp.scen2[201]
sd(exp.scen2[,201])
avg.exp.scen3[201]
sd(exp.scen3[,201])
avg.exp.scen4[201]
sd(exp.scen4[,201])
avg.hyp.scen1[201]
sd(hyp.scen1[,201])
avg.hyp.scen2[201]
sd(hyp.scen2[,201])
avg.hyp.scen3[201]
sd(hyp.scen3[,201])
```

```
avg.hyp.scen4[201]
sd(hyp.scen4[,201])

#NPV at year 20
mean(npv20.exp.scen1)
sd(npv20.exp.scen1)
mean(npv20.exp.scen2)
sd(npv20.exp.scen2)
mean(npv20.exp.scen3)
sd(npv20.exp.scen3)
mean(npv20.exp.scen4)
sd(npv20.exp.scen4)
mean(npv20.hyp.scen1)
sd(npv20.hyp.scen1)
mean(npv20.hyp.scen2)
sd(npv20.hyp.scen2)
mean(npv20.hyp.scen3)
sd(npv20.hyp.scen3)
mean(npv20.hyp.scen4)
sd(npv20.hyp.scen4)

#NPV at year 50
mean(npv50.exp.scen1)
sd(npv50.exp.scen1)
mean(npv50.exp.scen2)
sd(npv50.exp.scen2)
mean(npv50.exp.scen3)
sd(npv50.exp.scen3)
mean(npv50.exp.scen4)
sd(npv50.exp.scen4)
mean(npv50.hyp.scen1)
sd(npv50.hyp.scen1)
mean(npv50.hyp.scen2)
sd(npv50.hyp.scen2)
mean(npv50.hyp.scen3)
sd(npv50.hyp.scen3)
mean(npv50.hyp.scen4)
sd(npv50.hyp.scen4)

#NPV at year 100
mean(npv100.exp.scen1)
sd(npv100.exp.scen1)
mean(npv100.exp.scen2)
sd(npv100.exp.scen2)
mean(npv100.exp.scen3)
sd(npv100.exp.scen3)
mean(npv100.exp.scen4)
sd(npv100.exp.scen4)
mean(npv100.hyp.scen1)
sd(npv100.hyp.scen1)
mean(npv100.hyp.scen2)
sd(npv100.hyp.scen2)
mean(npv100.hyp.scen3)
sd(npv100.hyp.scen3)
mean(npv100.hyp.scen4)
sd(npv100.hyp.scen4)

#NPV at year 200
```

```
mean(npv200.exp.scen1)
sd(npv200.exp.scen1)
mean(npv200.exp.scen2)
sd(npv200.exp.scen2)
mean(npv200.exp.scen3)
sd(npv200.exp.scen3)
mean(npv200.exp.scen4)
sd(npv200.exp.scen4)
mean(npv200.hyp.scen1)
sd(npv200.hyp.scen1)
mean(npv200.hyp.scen2)
sd(npv200.hyp.scen2)
mean(npv200.hyp.scen3)
sd(npv200.hyp.scen3)
mean(npv200.hyp.scen4)
sd(npv200.hyp.scen4)


##95% confidence
#NPV at year 20
t.test(npv20.exp.scen1, npv20.hyp.scen1)
t.test(npv20.exp.scen2, npv20.hyp.scen2)
t.test(npv20.exp.scen3, npv20.hyp.scen3)
t.test(npv20.exp.scen4, npv20.hyp.scen4)

#NPV at year 50
t.test(npv50.exp.scen1, npv50.hyp.scen1)
t.test(npv50.exp.scen2, npv50.hyp.scen2)
t.test(npv50.exp.scen3, npv50.hyp.scen3)
t.test(npv50.exp.scen4, npv50.hyp.scen4)

#NPV at year 100
t.test(npv100.exp.scen1, npv100.hyp.scen1)
t.test(npv100.exp.scen2, npv100.hyp.scen2)
t.test(npv100.exp.scen3, npv100.hyp.scen3)
t.test(npv100.exp.scen4, npv100.hyp.scen4)

#NPV at year 200
t.test(npv200.exp.scen1, npv200.hyp.scen1)
t.test(npv200.exp.scen2, npv200.hyp.scen2)
t.test(npv200.exp.scen3, npv200.hyp.scen3)
t.test(npv200.exp.scen4, npv200.hyp.scen4)


##90% confidence
#NPV at year 20
t.test(npv20.exp.scen1, npv20.hyp.scen1, conf.level=0.9)
t.test(npv20.exp.scen2, npv20.hyp.scen2, conf.level=0.9)
t.test(npv20.exp.scen3, npv20.hyp.scen3, conf.level=0.9)
t.test(npv20.exp.scen4, npv20.hyp.scen4, conf.level=0.9)


#NPV at year 50
t.test(npv50.exp.scen1, npv50.hyp.scen1, conf.level=0.9)
t.test(npv50.exp.scen2, npv50.hyp.scen2, conf.level=0.9)
t.test(npv50.exp.scen3, npv50.hyp.scen3, conf.level=0.9)
t.test(npv50.exp.scen4, npv50.hyp.scen4, conf.level=0.9)
```

```
#NPV at year 100
t.test(npv100.exp.scen1, npv100.hyp.scen1, conf.level=0.9)
t.test(npv100.exp.scen2, npv100.hyp.scen2, conf.level=0.9)
t.test(npv100.exp.scen3, npv100.hyp.scen3, conf.level=0.9)
t.test(npv100.exp.scen4, npv100.hyp.scen4, conf.level=0.9)

#NPV at year 200
t.test(npv200.exp.scen1, npv200.hyp.scen1, conf.level=0.9)
t.test(npv200.exp.scen2, npv200.hyp.scen2, conf.level=0.9)
t.test(npv200.exp.scen3, npv200.hyp.scen3, conf.level=0.9)
t.test(npv200.exp.scen4, npv200.hyp.scen4, conf.level=0.9)


##80% confidence
#NPV at year 20
t.test(npv20.exp.scen1, npv20.hyp.scen1, conf.level=0.8)
t.test(npv20.exp.scen2, npv20.hyp.scen2, conf.level=0.8)
t.test(npv20.exp.scen3, npv20.hyp.scen3, conf.level=0.8)
t.test(npv20.exp.scen4, npv20.hyp.scen4, conf.level=0.8)


#NPV at year 50
t.test(npv50.exp.scen1, npv50.hyp.scen1, conf.level=0.8)
t.test(npv50.exp.scen2, npv50.hyp.scen2, conf.level=0.8)
t.test(npv50.exp.scen3, npv50.hyp.scen3, conf.level=0.8)
t.test(npv50.exp.scen4, npv50.hyp.scen4, conf.level=0.8)

#NPV at year 100
t.test(npv100.exp.scen1, npv100.hyp.scen1, conf.level=0.8)
t.test(npv100.exp.scen2, npv100.hyp.scen2, conf.level=0.8)
t.test(npv100.exp.scen3, npv100.hyp.scen3, conf.level=0.8)
t.test(npv100.exp.scen4, npv100.hyp.scen4, conf.level=0.8)

#NPV at year 200
t.test(npv200.exp.scen1, npv200.hyp.scen1, conf.level=0.8)
t.test(npv200.exp.scen2, npv200.hyp.scen2, conf.level=0.8)
t.test(npv200.exp.scen3, npv200.hyp.scen3, conf.level=0.8)
t.test(npv200.exp.scen4, npv200.hyp.scen4, conf.level=0.8)




###plots comparing exp and hyp functions for each discounting scenario
plot(avg.exp.scen1, type= "l", col="black", lwd=2, xlab="Year from Present",
      ylab="Present Value", main="Average Present Value for 7.0% real
      discount rate (8.5% nominal rate)", xlim=c(0,200), ylim=c(0,10000))
lines(avg.hyp.scen1, lwd=2, col="gray50")
abline(v=yr.max.diff.scen1, lwd=2, lty=3, col="gray30")
text(x=15, y=100, labels="Exp", col="black")
text(x=60, y=2600, labels="Hyp", col="gray50")

plot(avg.exp.scen2, type= "l", col="black", lwd=2, xlab="Year from Present",
      ylab="Present Value", main="Average Present Value for 3.5% real
      discount rate (5.0% nominal rate)", xlim=c(0,num.years),
      ylim=c(0,10000))
lines(avg.hyp.scen2, lwd=2, col="gray50")
abline(v=yr.max.diff.scen2, lwd=2, lty=3, col="gray30")
text(x=20, y=1000, labels="Exp", col="black")
```

```
text(x=70, y=3200, labels="Hyp", col="gray50")

plot(avg.exp.scen3, type= "l", col="black", lwd=2, xlab="Year from Present",
      ylab="Present Value", main="Average Present Value for 3.0% real
      discount rate (4.5% nominal rate)", xlim=c(0,num.years),
      ylim=c(0,10000))
lines(avg.hyp.scen3, lwd=2, col="gray50")
abline(v=yr.max.diff.scen3, lwd=2, lty=3, col="gray30")
text(x=20, y=1000, labels="Exp", col="black")
text(x=90, y=3000, labels="Hyp", col="gray50")

plot(avg.exp.scen4, type= "l", col="black", lwd=2, xlab="Year from Present",
      ylab="Present Value", main="Average Present Value for 0% real discount
      rate (1.5% nominal rate)", xlim=c(0,num.years), ylim=c(0,10000))
lines(avg.hyp.scen4, lwd=2, col="gray50")
text(x=50, y=2500, labels="Exp", col="black")
text(x=80, y=5000, labels="Hyp", col="gray50")


###impacts of discount rate on exponentially discounted PV's
plot(avg.exp.scen4, type= "l", col="gray70", lwd=3, xlab="Year from Present",
      ylab="Present Value", main="Average Present Value comparison for all
      rates (exponential)", xlim=c(0,200), ylim=c(0,10000))
lines(avg.exp.scen3, lwd=3, col="gray50")
lines(avg.exp.scen2, lwd=3, col="gray30")
lines(avg.exp.scen1, lwd=3, col="black")
legend(150,7000,c("7.0%","3.5%","3.0%","0%"),lwd=2,col=c("black","gray30",
      "gray50","gray70"),cex=.75, bty="n")


###impacts of discount rate on hyperbolically discounted PV's
plot(avg.hyp.scen4, type= "l", col="gray70", lwd=3, xlab="Year from Present",
      ylab="Present Value", main="Average Present Value comparison for all
      rates (hyperbolic)", xlim=c(0,200), ylim=c(0,10000))
lines(avg.hyp.scen3, lwd=3, col="gray50")
lines(avg.hyp.scen2, lwd=3, col="gray30")
lines(avg.hyp.scen1, lwd=3, col="black")
legend(150,7000,c("7.0%","3.5%","3.0%","0%"),lwd=2,col=c("black","gray30",
      "gray50","gray70"),cex=.75, bty="n")


###plots displaying the loss of NPV between exponential and hyperbolic
discount functions for each rate
##7.0%
plot(avg.exp.scen1, type= "l", col="black", lwd=2, xlab="Year from Present",
      ylab="Present Value", main="Loss of Net Present Value for 7.0% real
      discount rate", xlim=c(0,200), ylim=c(0,10000))
lines(avg.hyp.scen1, lwd=2, col="gray50")
polygon(c(1:num.years, num.years:1), c(avg.exp.scen1, rev(avg.hyp.scen1)),
      border=NA, density= 10, col="gray50")
polygon(c(1:num.years, num.years:1), c(avg.exp.scen1, rep(0, num.years)),
      border=NA, density=20, col="black")

##3.5%
plot(avg.exp.scen2, type= "l", col="black", lwd=2, xlab="Year from Present",
      ylab="Present Value", main="Loss of Net Present Value for 3.5% real
      discount rate", xlim=c(0,200), ylim=c(0,10000))
lines(avg.hyp.scen2, lwd=2, col="gray50")
```

```
polygon(c(1:num.years, num.years:1), c(avg.exp.scen2, rev(avg.hyp.scen2)),
      border=NA, density= 10, col="gray50")
polygon(c(1:num.years, num.years:1), c(avg.exp.scen2, rep(0, num.years)),
      border=NA, density=20, col="black")

##3.0%
plot(avg.exp.scen3, type= "l", col="black", lwd=2, xlab="Year from Present",
      ylab="Present Value", main="Loss of Net Present Value for 3.0% real
      discount rate", xlim=c(0,200), ylim=c(0,10000))
lines(avg.hyp.scen3, lwd=2, col="gray50")
polygon(c(1:num.years, num.years:1), c(avg.exp.scen3, rev(avg.hyp.scen3)),
      border=NA, density= 10, col="gray50")
polygon(c(1:num.years, num.years:1), c(avg.exp.scen3, rep(0, num.years)),
      border=NA, density=20, col="black")

##0%
plot(avg.exp.scen4, type= "l", col="black", lwd=2, xlab="Year from Present",
      ylab="Present Value", main="Loss of Net Present Value for 0% real
      discount rate", xlim=c(0,200), ylim=c(0,10000))
lines(avg.hyp.scen4, lwd=2, col="gray50")
polygon(c(1:num.years, num.years:1), c(avg.exp.scen4, rev(avg.hyp.scen4)),
      border=NA, density= 10, col="gray50")
polygon(c(1:num.years, num.years:1), c(avg.exp.scen4, rep(0, num.years)),
      border=NA, density=20, col="black")
```