Environmental compensation is the provision of natural resources through a restoration project, which is scaled to ensure the public is compensated for the environmental damage. Compensation is a human-centric concept aimed at society's well-being. This study's objective is to examine the social welfare implications of resource-based compensation using Habitat Equivalency Analysis (HEA) and Resource Equivalency Analysis (REA), with a focus on the distributive impacts across society (intra-generational equity) and between generations (inter-generational equity).

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SLU generates knowledge for the sustainable use of biological natural resources. Research, education, extension, as well as environmental monitoring and assessment are used to achieve this goal.

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Environmental Compensation Using Resource Equivalency Analysis (REA) and Habitat Equivalency Analysis (HEA): Is it Just for the Birds ?

Determining Whether Society is Better Off Following Resource-Based Compensation

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Licentiate Thesis
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Cover: An adult sea eagle (*Haliaeetus albicilla*) found under Turbine #61 on April 16, 2008. A total of 32 sea eagles have been found under turbines at the Smøla wind farm in Norway between 2005 and April 2010.
(photo: Espen Lie Dahl, Norwegian Institute for Nature Research)

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Environmental compensation using Resource Equivalency Analysis (REA) and Habitat Equivalency Analysis (HEA): Is it just for the birds ?

Abstract

Environmental compensation is the provision of natural resources through a restoration project, which is scaled to ensure the public is compensated for the environmental damage. The European Union (EU) recently implemented the Environmental Liability Directive (ELD), requiring that environmental damage be remediated (restored) so that the affected environment returns to (or toward) its baseline condition and the public is compensated for the initial damage and the losses during the time it takes for the environment to recover (interim losses). Equivalency Analysis (EA) represents a method for scaling compensation to offset interim losses. Compensation is a human-centric concept aimed at society's well-being which, among other things, depends upon a flow of environmental services (e.g., biodiversity, nutrient and carbon cycling, provision of recreation, etc). This study considers compensation scaled using a non-monetary (ecologic) metric, as in a Habitat Equivalency Analysis (HEA) or a Resource Equivalency Analysis (REA). Both HEA and REA assume the utility change associated with environmental damage and subsequent restoration is proportional to changes in an ecologic metric (e.g., acres of habitat, number of birds, etc). This study's objective is to examine the social welfare implications of resource-based compensation, with a focus on the distributive impacts across society (intra-generational equity) and between generations (inter-generational equity). Paper I develops an illustrative and hypothetical case study to demonstrate how one might apply EA to the case of bird mortality associated with wind power development. Paper II argues for the use of EA to scale resource-based compensation within the existing Environmental Impact Assessment hierarchy of impacts: *avoid-minimize-compensate,* with a particular focus on wind power development.

Keywords: Equivalency Analysis, environmental compensation, welfare economics, environmental liability

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Dedication

I dedicate this thesis to my wife Emma for supporting me when I needed it the most.

The coincidence of prefixes in the two subjects is thoroughly appropriate. The Greek root means household and it signifies an interacting set of individual activities, both complementary and competitive with each other. The predator benefits from the growth in both numbers

and individual size of the prey, yet one cannot say the relation is entirely beneficial to the latter. One nation may gain from the growth in other nations from increased exports to them but also lose as they compete for scarce resources such as oil.

— Kenneth Arrow (1972) Nobel prize winner in economics in a guest editorial entitled "Eco(nomics/logy)" in the journal "Ecological Research"

"We should not knowingly allow any species or race to go extinct. And let us go beyond mere salvage to begin the restoration of natural environments, in order to enlarge wild populations and stanch the hemorrhaging of biological wealth. There can be no purpose more enspiriting than to begin the age of restoration, reweaving the wondrous diversity of life that still surrounds us."

— E.O. Wilson (1992) The Diversity of Life

Contents

List of Publications

This thesis is supported in part by work contained in the following papers, referred to by Roman numerals in the text:

I Cole, Scott (2009). "How much is enough? Determining adequate levels of environmental compensation for wind power impacts using equivalency analysis: An illustrative & hypothetical case study of sea eagle impacts at the Smøla Wind Farm, Norway." *Proceedings of the Offshore Wind 2009 Conference*. Stockholm. 14 September 2009.

II Cole, Scott (2010). Wind power compensation is not for the birds: An opinion from an environmental economist. *Journal of Restoration Ecology*. (Article accepted for publication pending revisions).

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Abbreviations

AWWI	American Wind and Wildlife Institute
Bys	Bird Years
CBA	Cost-benefit analysis
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act (US)
CV	Compensating Variation
DBYs	Discounted Bird Years
DSHaYs	Discounted Service Hectare Years
EA	Equivalency Analysis
EIA	Environmental Impact Assessment
ELD	Environmental Liability Directive
EU	European Union
EV	Equivalency Variation
HEA	Habitat Equivalency Analysis
HH	Household
NINA	Norway Institute for Nature Research
OPA	Oil Pollution Act (US)
PPP	Polluter pays policy
REA	Resource Equivalency Analysis
REMEDE	Resource Equivalency Methods for Assessing Environmental Damage in the EU (www.envliability.eu)
SWF	Social welfare function
VEA	Value Equivalency Analysis
VPP	Victim pays policy
WTA	Willingness to accept
WTP	Willingness to pay

1 Introduction

There is an increasing need for governments to measure and assess the human welfare impacts of ecological change. Specifically, there is a demand to improve upon methods that quantify the effects of ecological change in ways that facilitate the valuation of that change by economists, for final use by policy-makers. Such methods are commonly used in environmental Cost-Benefit Analysis (CBA) where, for example, policy-makers may want to evaluate the potential net benefits to society of a new road, bridge, wind farm development or other infrastructure project. But such methods are equally important -- and in equally high demand -- for assessing the magnitude of environmental damage for the purpose of scaling appropriate amounts of environmental compensation (ten Kate 2004; McKenney 2005; Englen 2008).

Environmental compensation refers to the provision of environmental resources to offset environmental damage. In contrast to financial compensation, where the compensation mechanism is a cash payment, the focus here is on the use of environmental resources provided through a restoration or preservation project (hereafter: restoration project). For example, the unintended release of oil into a wetland may lead to the provision of environmental compensation in the form of either (a) improving the on-site post-spill level of environmental services through habitat restoration; (b) purchasing and protecting a nearby wetland threatened by development; or (c) re-constructing a wetland (on- or off-site) that provides similar services to the one damaged by the spill. Another example may focus on lost recreational use (e.g., reduced fishing days) following a chemical spill at a popular sport fishing lake. Compensation in this case may involve improving the fishery (on- or off-site) or improving public access at alternative fishing sites. A third example of compensation is provided in Paper I, where impacts on sea eagle populations from a wind farm may be compensated through a project to reduce sea eagle electrocution at nearby power lines.[1]

All three compensation examples above could be scaled using **Equivalency Analysis**, (EA), which is a general method that aims for equivalence between damaged and restored resources, where equivalency may be measured in terms of money (**Value Equivalency Analysis**, VEA) or in terms of a non-monetary metric (**Habitat Equivalency Analysis**, HEA, or **Resource Equivalency Analysis**, REA). We explain these approaches in more detail below.

Environmental compensation requirements are on the rise globally. Under a number of US statues and international treaties (Mason, 2003) compensatory restoration is mandatory following environmental accidents such as chemical releases (*ex post* compensation). More recently, the European Union (EU) implemented the Environmental Liability Directive (ELD), requiring that environmental damage be remediated (restored[2]) so that the affected environment returns to (or toward) its baseline condition and the public is compensated for the initial damage and the losses during the time it takes for the environment to recover (interim losses). In other cases, compensation may be required before undertaking development projects (*ex ante* compensation) (Banverket 2006). There are also examples of environmental compensation to facilitate permit approval, so-called "permitted injuries" in exchange for environmental improvements on- or off-site (Allen et al 2005; Peacock 2007). Finally, governments are increasingly concerned about the rate of global biodiversity decline (ten Kate, 2004; McKenney 2005). Biodiversity offsets represent a compensation mechanism aimed at addressing society's ecological loss (Ozdemiroglu 2009).

While there are several synonyms and emerging buzzwords for the idea behind environmental compensation (see Table 1), this study assumes two distinguishing characteristics. First, environmental compensation encompasses the entire process of quantifying the extent of (actual or predicted) environmental damage and then scaling a restoration project to an appropriate size to adequately offset that

[1] For a Swedish example of ex ante environmental compensation, see the Botniabana railroad project (Banverket 2006). Rundcrantz (2006) summarizes compensation within Swedish road construction.

[2] See footnote 1 in Table 1.

damage. Second, the underlying assumption of environmental compensation is that the primary beneficiary is society itself ("the public"). That is, compensation is first and foremost a human-centric concept aimed at society's well-being or, more specifically, the well-being of individuals within society. This is consistent with the generally accepted social norm that if an individual is harmed, that harm can be offset -- compensated -- by providing the individual with something in lieu of his/her first choice. The same concept applies when the public loses environmental resources, or the services derived from those resources.

It is worth remembering that environmental damage per se does not have meaning in a world devoid of human existence. Indeed, 'sustainability' is an anthropocentric idea and would not exist as a concept without mankind.[3] This human-centric view has implications for the EA approach analyzed in this paper. We assume that because we are the decision-makers of today, we will base our decisions on how changes (environmental and otherwise) affect our well-being, including the well-being of future generations.

Table 1 Alternative words to describe the concept of environmental compensation

• compensatory/complementary remediation or restoration[1] • biodiversity offsets • environmental restoration, rehabilitation or replacement • acquiring the equivalent of	• compensation ratios • "no net loss" (e.g., biodiversity) • "net gain" (e.g., biodiversity) • compensatory mitigation[2] • compensatory measures • environmental liability

[1] Note that US laws requiring environmental compensation refer to "restoration" while the EU's ELD refers instead to "remediation" (which has a slightly different meaning in the US, where the term refers to cleaning or removing contaminants). To avoid confusion, I use the term "restoration" although practitioners should be aware that remediation is preferred in the European context.

[2] Compensatory mitigation is often used in the US to refer to environmental compensation. However, I use the term *mitigation* to refer to activities that minimize (make less severe) an environmental impact. In contrast, *compensation* provides offsetting gains to residual environmental impacts that cannot be avoided or mitigated.

[3] Some argue that ecological integrity should be maintained 'for its own sake,' but this is, in itself, a reflection of individual (or societal) preferences.

Environmental compensation's focus on offsetting human welfare losses -- rather than pure ecological losses -- need not preclude ecological (or even ethical) motivations for the compensation. Besides income and the consumption of private goods, society's welfare depends critically on the availability of ecosystem services both for the current and future generation (e.g., biodiversity, nutrient and carbon cycling, water purification, flood control, provision of recreation etc). Further, one may posit that mankind shoulders an ethical responsibility to protect species and their habitat. However, the focus on human welfare will, in most cases[4], address these ancillary issues because restoration projects that compensate for human welfare losses inevitably benefit ecological resources, while also demonstrating an ethical responsibility.

The legal requirements for environmental compensation discussed above are unequivocally motivated by impacts on human welfare. For example, the Environmental Liability Directive requires compensatory restoration to address "interim losses" which "... result from the fact that the damaged natural resources and/or services are not able to perform their ecological functions or provide services to other natural resources or to the public..." (ELD, Annex II 1(d)).[5] Further, the Business and Biodiversity Offsets Programme (BBOP) also includes a focus on human welfare.[6] This point is important to keep in mind when we discuss alternative metrics for measuring the effect of environmental loss and gain -- the effect of interest is primarily on society's welfare rather than on ecological systems themselves. As we will discuss, this distinction can be blurred in the case of scaling compensation with a non-monetary (e.g., ecological) metric.

A number of economic ideas underlie the concept of environmental compensation and are implicit in this study, including the following:

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[4] The key assumption here is that an individual is adequately informed about how ecological loss affects his/her well-being. Given the extent of ecological research into the impacts of environmental loss on society and ecosystems, there is reason to believe that it is difficult, if not impossible, for a typical individual to be adequately informed.

[5] Requirements of other EU Directives dealing with environmental compensation may differ, see Section 5.

[6] From BBOP website: "The goal of biodiversity offsets is to achieve no net loss and preferably a net gain of biodiversity on the ground with respect to species composition, habitat structure, ecosystem function and people's use and *cultural values associated with biodiversity*" [*emphasis added*] (BBOP 2010 Program flyer)

- In a perfectly competitive market, government intervention in the form of environmental compensation requirements is superfluous. However, economists generally recognize the existence of market failures as a valid justification for governmental intrusion. In our case, the primary market failure is external effects, which leads producers to overproduce because of a failure to consider the full (environmental) costs of production. Social welfare losses accrue when these costs are external to firms' production decision. The EU's ELD is motivated by the Polluter Pays Principle (PPP),[7] which ensures polluters internalize the costs of environmental damage, thus providing incentives to prevent costly environmental damage in the future. As we will see, the provision of environmental restoration is a public good, which represents an additional market failure. The implication of this market failure is discussed in Section 5.
- The EA framework assumes that the "type, quality, and quantity" of compensatory resources provided to the public (see ELD, Annex II, 1.2.2) is based on social indifference curves (as in Figure 3) that measure the extent to which society is willing to trade-off (substitute) a restored resource for a damaged resource. Importantly, these social preferences lie behind the sought-after equivalency, rather than a perfect 'ecological match' between lost and gained resources. Distributional impacts -- i.e., the 'winners' and losers' in society that arise from restoration outcomes -- are also assumed to be a function of social preferences, both from an inter-generational (Section 4.2.3) and intra-generational perspective (Section 4.2.5).
- This study assumes that the HEA and REA framework is only applicable in the case of marginal changes to a damaged and restored resource (i.e., cases of species extinction or contamination of the 'last few acres of wetland' in a region are not suitable for the non-monetary approach). Non-marginal projects also present challenges when scaling compensation based on a monetary metric. We discuss the implications of non-marginal projects in Section 5 (see e.g., Figure 10).
- Finally, our framework is a deterministic approach, which does not explicitly take into account uncertainty as it relates to, for example, individual preferences or ecological outcomes. For example, rather

[7] Importantly, the Victim Pays Principle (VPP) is an equally efficient approach for addressing an externality, although it is often times criticized for not being "fair."

that explicitly accounting for future uncertainty as in a stochastic approach, EA generally considers uncertainty *ex post* through a sensitivity analysis of key parameters such as the discount rate, extent of ecological loss, years until ecological recovery, etc.

Economics is not the only relevant discipline: environmental compensation demands an interdisciplinary approach. Ecological expertise is critical in measuring environmental changes and conveying complex information, including the consequences of environmental change. Legal input is also critical to determining when and if compensation is required in specific cases. Finally, recent debate has focused on the ethical component of environmental compensation (Elliot 1997), namely that species themselves have a right to the services provided by environmental resources (e.g., habitat services such as food, protection, flow of energy, etc). Table 2 identifies some of the relevant questions addressed by the different disciplines in an environmental compensation assessment.

Table 2 Interdisciplinary contributions to an environmental compensation assessment
Economics
• identifies a means of measuring human well-being (utility) • measures the amount, type, or quality of a compensatory resource that an individual may be willing to substitute, or trade, in lieu of a damaged resource; • assesses how individuals trade-off restored vs. damaged resources across *time* and *space*; • highlights the distributional impacts of compensation on society • provides methods (when relevant) to value resource change in monetary terms (VEA)
Ecology
• identifies relevant and appropriate ecological metrics for measuring ecological change • collects and analyzes data to *quantify* the relevant ecological metric • conveys complex scientific information to the public and policy-makers • identifies and motivates the selection of compensatory restoration projects • monitors and reports on the success of restoration projects over time
Law (both international and national)
• provides the guidelines of restoration scaling methods (e.g., Annex II of the ELD) • assesses the type and scope of activities that face compensation requirements -- e.g., following a spill or prior to undertaking a development project • interprets legal doctrine to determine whether actual compensation is legally adequate

Ethical
• contributes to the debate regarding the role of human intervention in ecological systems, including whether restoration is feasible given our weak understanding of complex ecosystems (Hilderbrand et al 2005)

The practical issues of measuring appropriate amounts of environmental compensation is referred to as scaling compensation, i.e., "how much is enough." Over the last 30 years, the US has had extensive experience in scaling methods due to legal requirements for environmental compensation (English et al 2009). Since the mid-1990s the primary method for scaling compensation in the US has been EA. In Europe, the use of EA to scale compensation is likely to increase due to the requirements of several Directives aimed at environmental compensation.[8] To support Member States, the European Commission funded the REMEDE project[9], which formalizes the EA approach in a Toolkit (Lipton et al 2008). This Toolkit is directly applicable to scaling environmental compensation across a wide variety of environmental damage, and is the basis for the case study in Paper I.

As noted above, EA refers to a scaling approach that aims for equivalency between damage and compensation, though such equivalency may proceed under two alternative assumptions. A VEA measures the environmental loss and gain in social welfare using a monetary metric. That is, a monetary sum is attached to the loss using economic valuation techniques and compensation is scaled based on this information. Alternatively, an REA or HEA measures the environmental loss and gain in social welfare using a non-monetary (ecological) metric. *That is, rather than assigning a monetary sum to describe the value of the public's loss and gain, a non-monetary metric uses an ecological measure that is assumed to act as a proxy for the change in human welfare.[10]* This study focuses on the REA and HEA approach.

In contrast to VEA, REA and HEA are the preferred (and in the case of the US, most widespread) approaches in both the US and Europe. The

[8] In addition to the ELD, see also Habitat and Wild Birds and Environmental Impact Assessment Directives (see also www.envliability.eu).

[9] Resource Equivalency Methods for Assessing Environmental Damage in the EU (REMEDE) was funded by the Sixth Framework Programme of the European Commission (www.envliability.eu)

[10] An REA or HEA has also been referred to as a "resource-to-resource" or "service-to-service" approach, referring to the direct replacement of damaged resources/services with restored resources/services.

EU's Environmental Liability Directive (ELD) explicitly favors these approaches to compensation so long as the resources/services provided in compensation are of a similar "type, quality, and quantity." As noted in Table 2, resource-based compensation requires an interdisciplinary approach, not the least of which is an economic framework in which to assess human welfare. A cursory review of the non-monetary approach (REA/HEA) from a welfare economics perspective would seem to indicate that it is an inferior approach because it makes a number of assumptions about the utility (welfare) change associated with damage and restoration. This study will assess the economic implications of these assumptions.

The remaining part of this study is organized as follows. Section 2 summarizes the purpose and objective of this study. Section 3 provides additional background on the mechanics of the EA approach, discussing both the monetary and non-monetary approaches. Section 4 provides the theory behind 'economic compensation' which is based on individuals' observed behavior of trading off one good for another. Section 4 also interweaves a discussion of how the EA approach to environmental compensation follows or deviates from economic theory. Finally Section 5 discusses the implications of these deviations and what they mean for social welfare.

2 Purpose and Objective

The purpose of this thesis is to examine critically the economic assumptions underlying environmental compensation in the case of Habitat Equivalency Analysis (HEA) and Resource Equivalency Analysis (REA). Specifically, I will address the following:

- identify the relevant micro and welfare economic theory that supports economic compensation, which lays the foundation for environmental compensation;
- identify the economic implications (e.g., effect on welfare) of providing resource-based environmental compensation using a non-monetary (ecological) metric for scaling purposes. Specifically, this means a focus on HEA and REA, rather than Value Equivalency Analysis (VEA);
- focus in particular on the issues of welfarism, the social welfare function (intra-generational equity) and the implications of discounting resource units (inter-generational equity);
- develop an illustrative case study of equivalency analysis and draw conclusions and lessons learned (see Paper I); and
- provide economic interpretations of the equivalency analysis approach to environmental compensation for ecologists and other non-economists (see Paper II).

3 Background: Equivalency Analysis (EA)

This section provides some background into the development of Equivalency Analysis (EA) -- under the case of both monetary and non-monetary metrics -- as well as a description of key terms and concepts. It also describes the five steps in conducting an equivalency analysis. These concepts are key to understanding the economic theory section that follows.

Environmental compensation requirements in the US arise from CERCLA and OPA[11], which require that compensation be provided to "make the public whole" following oil and chemical spills. One of the first examples Equivalency Analysis (EA) arose from the Exxon Valdez oil spill in Alaska and was based on a Value Equivalency Analysis (VEA) approach. A nationwide contingent valuation survey of Americans estimated the lost use and non-use monetary values by asking individuals how much they would be willing to pay to prevent a similar event from occurring again in the future (Carson et al 2003). Extrapolating across all households in the US, the study estimated a shocking three billion dollars of lost value. These results were used to inform the extent of actual expenditures[12] on environmental restoration projects in Alaska to compensate welfare loss to the American public.[13]

[11] The Comprehensive Environmental Response, Compensation and Liability Act, CERCLA (U.S. Code, Title 42, Chapter 103) and Oil Pollution Act, OPA (U.S. Code, Title 33, Chapter 40)

[12] This VEA approach is referred to as "value to cost", while a "value to value" would instead ensure that the value of restoration projects undertaken were equivalent to the lost value.

[13] A negotiated agreement led Exxon to agree to spend one billion dollars on restoration projects (Carson et al 2003).

The fallout from this high-profile case of environmental compensation based on economic valuation led to an alternative approach. The Resource (or Habitat) Equivalency Analysis approach was developed by environmental economists and the first known application was Unsworth and Bishop (1994). The authors assumed that the information on the value of an environmental resource is either not available or too difficult to obtain and focused instead on an ecological quantity (e.g., acres of contaminated land, number of fish/birds killed, etc) as the basis for measuring loss and gain, while accounting for the impact of time. They argued that survey respondents asked to value a resource change do not have – nor can they reasonably be expected to synthesize – all of the information about the resource and the ecosystem to provide an accurate response. Since this time, a number of court cases in the US have confirmed the validity of the habitat equivalency approach for scaling compensatory restoration (US v. Fisher 1992); US v Great Lakes Dredge and Dock et al 2001) as well as the concept of interim loss (US v Union Pacific Railroad 2008). Furthermore, the ELD is the first EU Directive to identify a framework for environmental compensation that explicitly prefers this resource-based scaling approach.

The US government provided guidance on conducting EA in 1996 (Reinharz and Burlington, 1996). Following passage of the Environmental Liability Directive in Europe, the European Commission developed a Toolkit to help Member States implement equivalency analysis.[14] The section below relies upon this Toolkit and Ozdemiroglu (2009) to summarize the key concepts.

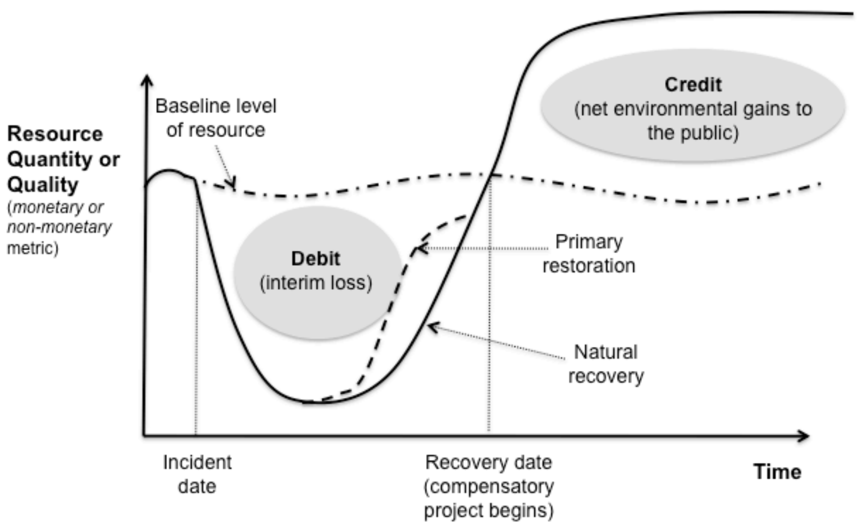
3.1 The language of environmental compensation

Figure 1 illustrates equivalency analysis by displaying the impact of environmental damage measured with either a monetary or non-monetary metric (Y axis) over time (X axis). Following an incident, environmental quality declines from its pre-spill condition and recovers over time to (or toward) its ecological baseline. During the time the resource is measurably below its baseline condition an interim loss (debit) has accrued to the public (On a side note, some damage may never recover to baseline, indicating that the interim loss

[14] The REMEDE project completed a Toolkit in 2008. Lipton et al (2008) is available on the web.

will continue into perpetuity. EA can also scale perpetual loss and gain, see Section 4.2.5.3). An off-setting environmental gain must be provided to ensure the public is adequately compensated. This net gain is referred to as the credit, which may represent a net gain over the baseline of the damaged site (on-site), or a net gain over the baseline of an alternative site (off-site). EA scales the size of the credit to ensure equivalence with the debit. Figure 1 shows a specific scenario where compensatory gains begin after the damaged site has recovered, but in practice restoration gains may sometimes begin accruing shortly after the incident date. Importantly, debit and credit impacts almost always occur over differing temporal horizons, which we address in Section 4.2.5.

Figure 1 The Anatomy of a Debit and Credit in Equivalency Analysis



Repairing environmental damage is generally divided into three types of restoration.[15] First, primary restoration consists of measures on-site to speed recovery of a damaged environment to (or toward) its baseline condition (e.g., removing, containing, cleaning up contaminants; re-vegetating damaged areas; restricting activity causing damage etc). In contrast to these purely ecological goals, the

[15] I use the word "restoration" while the REMEDE Toolkit prefers "remediation."

other two types of restoration described below are aimed at improving human welfare by creating "net resource benefits" to offset losses; thus, primary restoration does not require equivalency. However, the scale and efficacy of primary restoration (which may include natural recovery) affects the size of the interim loss and therefore influences the debit calculation (Figure 1). Second, complementary restoration is required when primary restoration is not able to return the resource to its original baseline condition, which is the case as drawn in Figure 1. This type of restoration is usually aimed at improving a resource or service off-site and equivalency between the debit and the credit must be established. Finally, the third type is compensatory restoration which is required to offset the size of the interim loss. Such restoration often improves a similar resource located off-site, which means equivalency is required between the debit and the credit.

Thus, equivalency analysis determines the scope of complementary and compensatory restoration required to compensate the public (given the impact of primary restoration).

Ensuring equivalence between the damaged and restored resources also requires consideration of how time might affect the value of consuming[16] a resource. This is particularly important when the X axis in Figure 1 covers a long time period. For example, there is no reason to believe that an individual values the loss of a wetland today the same as the loss of a wetland in 100 years -- the former is likely a greater loss because he or she may not be around in 100 years to 'suffer' that loss. Thus, humans are inherently impatient and prefer to consume a resource today, rather than wait. But another reason why time affects value relates to the "cost" of consumption. In general, consuming something today costs money (traveling to, viewing, or directly using a resource costs money). If that consumption is postponed, that money could be used (invested) to produce some other consumption benefits in the future (i.e., consuming today implies less of something tomorrow). Thus, impatience and the cost of consumption implies that the value of a natural resource in 'today's value' declines over time. If we want to compare the value of, say, a damaged resource today and a restored resource in 50 years, we need to adjust (standardize) that value. We do this through the use of a

[16] We use "consume" in a general sense. As discussed below, a public environmental good can be consumed by many without reducing the quantity available for others to also consume.

present value multiplier (analogous to a currency conversion rate). The multiplier is based on an assumed discount rate (Section 4.2.5).

The baseline in Figure 1 identifies the quantity or quality of a resource (or environmental service derived from that resource) over time. Importantly it shows the physical, biological, or ecological functions of a resource, as well as any use or nonuse human services provided by the resource, had the damage not occurred. Because it provides the basis for measuring the extent of the interim loss, characterizing the baseline is very important and should include dynamic changes likely to have occurred in the absence of the damage (data permitting). If pre-spill ecological or economic data are not available to characterize the baseline, alternative methods such as environmental modeling or "reference sites" can be used.

Importantly, an equivalency analysis (including the baseline) can be defined in terms of a monetary or non-monetary metric, as indicated by the Y axis in Figure 1. While the choice of metric varies considerably from one equivalency analysis to another, it must be the same for any given analysis on both the debit and credit side of the equivalency equation. There are two categories of metrics: a monetary metric measures the consumer surplus or other indirect monetary measure of utility loss and gain in monetary terms.[17] A non-monetary metric measures an ecological quantity as an assumed proxy for the utility loss and gain. Because ecological data is diverse and ranges from simple species counts to complex habitat indices, such metrics are chosen with a simplifying assumption; namely, restoration based on the chosen metric will collaterally address other ecological processes or species not directly quantified in the debit. Selection of the metric determines the type of equivalency analysis:

- If a non-monetary metric is expressed in terms of resource units (such as number of fish or birds), the analysis is called a Resource Equivalency Analysis (REA). Here, damage is measured in terms of the reduction in the chosen resource units and restoration is measured in terms of the increase in the chosen resource units. The attached case study represents an REA using a non-monetary metric of "bird-years."

[17] In the Exxon Valdez case the monetary metric included non-use and existence values, although in damage cases involving direct human use a consumer surplus measure is often used.

- If a non-monetary metric is expressed in terms of habitats or ecosystem services[18], the analysis that follows is called Habitat Equivalency Analysis (HEA). Here damage is measured as both (1) the area of habitat(s) damaged and (2) the degree of damage in terms of the percentage reduction in the ecosystem services typically provided in the baseline. Here a quantification metric is used to estimate the percentage loss/gain, e.g., % of contamination relative to an ecological threshold, % change in vegetation cover, % change in species abundance, density, biomass, etc. The benefit of restoration is measured in terms of area of habitat improved, based on the same quantification metric.
- If a monetary metric is used, the analysis that follows is called Value Equivalency Analysis (VEA). There are two variations to VEA. In the value – to – value variation, both damage and benefit of restoration are measured in monetary terms. In the value – to – cost variation, damage is measured in terms of the economic value lost. The restoration actions are then designed to cost at most as much as the monetary estimate of this value lost. 'Value' measured here refers to Total Economic Value[19] of the environment based on individuals' preferences for the use they make of the environment and for other non-use reasons. VEA is likely to be most appropriate when the nature, scale, or location of restoration projects differs from the specific resources and services damaged or if the damage results in a welfare loss to a significant user population (i.e., fishing, swimming, recreation, etc).

[18] The changes in each and every service cannot be quantified -- in part due to possible double-counting -- which leads to a proxy percentage loss or gain to simplify the analysis. Identification of key ecosystem services can be found in MEAB (2005).

[19] Total Economic Value is measured by individuals' willingness to pay (WTP) for an improvement or to avoid degradation in the quality and/or quantity of a resource or their willingness to accept compensation (WTA) to forgo an improvement or to tolerate degradation. There are several motivations for why individuals may have WTP and WTA for the environment: direct use value (consumption of resources or non-consumptive uses like recreation), indirect use value (ecosystem services that regulate the functioning of the environment), option value (for future uses of the environment) and non-use values (protecting the environment for others who make use of it now – altruistic value; for future generations – bequest value; and for the sake of the environment itself – existence value).

3.2 The five-step process for Equivalency Analysis (EA)

The conceptual approach of an equivalency analysis follows these basic actions:

- Add up the total debit (environmental damage) using a metric
- Quantify the per unit[20] environmental gain of restoration using the same metric (credit)
- Divide the total debit by the per unit gain to scale the appropriate amount of compensation

The formal procedure for an equivalency analysis suggested by the REMEDE Toolkit follows a slightly more comprehensive five-step methodology, applicable to an REA, HEA and VEA:

3.2.1 Step 1: Initial evaluation

A first step is to determine whether an equivalency analysis should be conducted and, if so, the appropriate scale and content of the analysis. This includes a search for available data to quantify damages and a consideration of relevant metrics.

3.2.2 Step 2: Quantify environmental damage (debit)

Damaged resources, habitats and/or services are identified and quantified relative to baseline conditions. The causes of damage are determined. Finally, the benefits of primary restoration are determined and the total debit (net of primary restoration) is quantified.

3.2.3 Step 3: Quantify environmental benefit of restoration (credit)

Credits are determined by identifying and evaluating potential restoration alternatives and by calculating the benefits that will be gained per unit of restored resource by implementing complementary and/or compensatory restoration projects.

3.2.4 Step 4: Scale restoration

The final step in the equivalency analysis per se is determining the scale or quantity of the restoration project(s) to implement. Scaling is performed so that, over time, the discounted flow of services from the restoration projects (credits) is equal to the total discounted loss (debits); that is, the two shaded areas in Figure 1 are equal.

[20] Note the importance of selecting restoration projects that can be scaled, i.e., continuously adjusted or proportioned. Purchasing land from a wetland bank that only sells 100 acre parcels is not scalable (unless the debit was conveniently in multiples of a hundred acres).

3.2.5 Step 5: Monitoring and reporting

After the equivalency analysis is performed and restoration projects are selected and scaled, a restoration plan is prepared that includes project goals, implementation details, engineering plans and designs, and biological plans and designs. The restoration plan also includes procedures and schedules for monitoring the recovery of resources and services following implementation, and evaluating the project's success.

Selecting an equivalency method, debit and credit metrics, and appropriate restoration often can be an iterative process. There is no objective standard for any of these components of an equivalency analysis – the 'right' approach is the one that achieves an appropriate amount and type of restoration most effectively. Regardless of the REM approach used, each step entails uncertainty either due to lack of data or incompleteness of our scientific and economic understanding of the way the environment functions.

Finally, the damaged resources and the restored resources are sometimes of differing quality or in different locations. The goal of compensatory/complementary restoration is to provide a resource or service of similar type, quality, or quantity. The key assumption in equivalency analysis is that we (humans) can restore, create, engineer, rehabilitate, or improve ecosystems -- even if our "restored systems" are not perfect replicas of the original. While some take issue with this assumption (Morris et al 2006; Hilderbrand et al 2005), the well-established use of equivalency analysis in the US -- as well as the recently completed REMEDE Toolkit -- demonstrates its credibility as an approach for estimating environmental compensation.

4 Theoretical Approach - Economic Compensation

This section describes the economic theory underlying "economic compensation." The micro and welfare economic principles discussed here provide a theoretical framework for "environmental compensation," even if the later deviates from theory in some respects. We identify these differences where relevant. We discuss the overall implications of these differences in Section 5.

Welfare economics studies the impact on individuals and society of policies, economic activity, or other changes that may affect human welfare. The tools of welfare economics can help us to evaluate -- though not necessarily provide objective answers to -- how to compensate an individual's utility loss (i.e., a decline in well-being[21]). We define "economic compensation" based on the concept of substitutability, i.e., that an individual can substitute one good for another good without affecting his/her utility. The most common choice for measuring the extent of a loss is money. However, through the assumption of substitutability, compensation can equally-well be measured in terms of the quantity of a good (i.e., the substitution of a damaged resource for a restored resource).

[21] Throughout this study we assume ordinal, rather than cardinal utility functions. That is, we assume individuals can rank preferred outcomes as preferred or not preferred (just as a thermometer ranks temperature as colder and warmer), but cannot attach a unique and meaningful 'utility score' to each outcome (Johansson 1991). The implication is that we cannot compare the value of one person's utility to another. Instead, we require a social welfare function which, at least in theory, provides a complete and consistent ranking of social outcomes by evaluating the trade-off in utility between households in society (see Section 4.2.3).

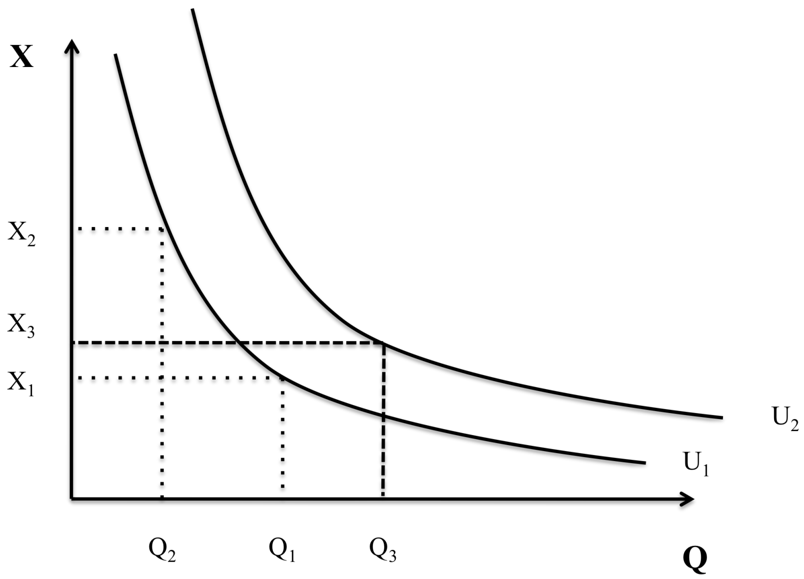
Below we show how the welfare economic principles provide us with a theoretically correct approach for measuring, or scaling, environmental compensation in terms of a monetary metric or a non-monetary metric. We begin by describing the key economic assumptions underlying compensation -- namely individual indifference curves and substitution. We expand this to the case of social indifference curves underlying equivalency analysis. To illustrate the issues of measuring and providing economic compensation we address five key methodological questions, with a particular focus on determining the implications for resource-based equivalency approaches to compensation.

4.1 Indifference curves and substitution

We begin with a simple starting point: individuals wish to consume (demand) certain goods, which firms are willing to produce (supply) at different prices. The basic assumption is that individuals choose to consume goods that maximize their well-being, or utility. In our simple example we assume individuals maximize their utility by demanding (1) private goods and services purchased in the market and (2) environmental goods and services that cannot be purchased in a market. We are interested in estimating how to compensate an individual when they cannot consume an environmental good due to environmental damage.

In order to study an individual's choice between private and environmental goods, we need to measure individual preferences for the type and amounts of each. To do this, we assume individuals prefer a certain bundle of private goods, which we refer to as X, and non-market environmental goods, referred to as Q. It is assumed that an individual's preference for each of these two goods can be described using an indifference curve as in Figure 2. These curves show an individual's preferences by indicating the amount of X and Q for which they are indifferent. In other words, individuals have an equal level of utility if they consume Q_1 and X_1, as they do with Q_2 and X_2. However, they are clearly better off with Q_3 and X_3. Thus, Figure 2 shows both the relative utility and the absolute utility between goods.

Figure 2 Individual indifference curves

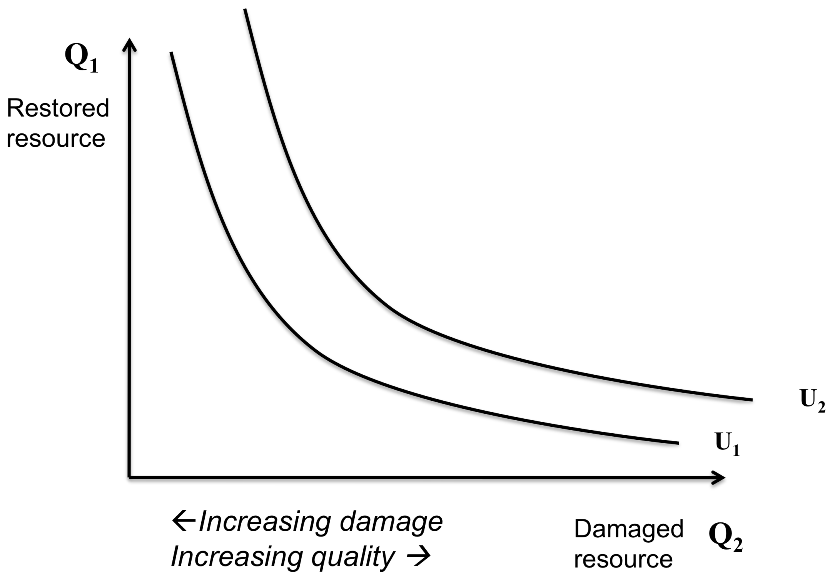


The key assumption is that individuals can substitute across goods and still maintain the same level of well-being, or utility. It is assumed that if the quantity of the environmental good, Q, is decreased, then it can be compensated for by an increase in the quantity of the private good, X, (or equivalently, money, which can purchase the private good) and that the individual is entirely indifferent between these alternative combinations of goods (the inverse is also true). Note also that the curves slowly approach each axis without ever touching the axes, indicating that substitution possibilities are always available. This assumption can easily be changed (as described in Figure 4 below).

However simple the assumption of substitutability, it underlies the majority of economic models that estimate individual choice (Freeman III 2003a). Trade-offs are evident in everyday life: when the price of a good increases, individuals tend to substitute away from that good and toward another (less expensive) good providing a similar level of utility; in the labor market individuals weigh the increased risk associated with certain employment (e.g., coal mining) with the increased salary.

Figure 3 illustrates the EA version of Figure 2, but on a societal level. This diagram demonstrates the trade-off implicit in equivalency analysis: the X-axis represents the damaged environmental resource (Q_2) and the Y-axis represents the restored environmental resource (Q_1). Equivalency analysis implicitly assumes that society is willing to trade-off a damaged environment with a restored environment.[22] As above, higher indifference curves indicate a higher level of social utility (e.g., more of both resources is preferred). In Figure 3, on the X-axis there is less damage (or more of the resource in good quality) as you move right: less damage requiring less restoration. The specific shape of these curves will be discussed in Section 5 (see "constant values across quantities").

Figure 3 Social indifference curves underlying Equivalency Analysis (EA)

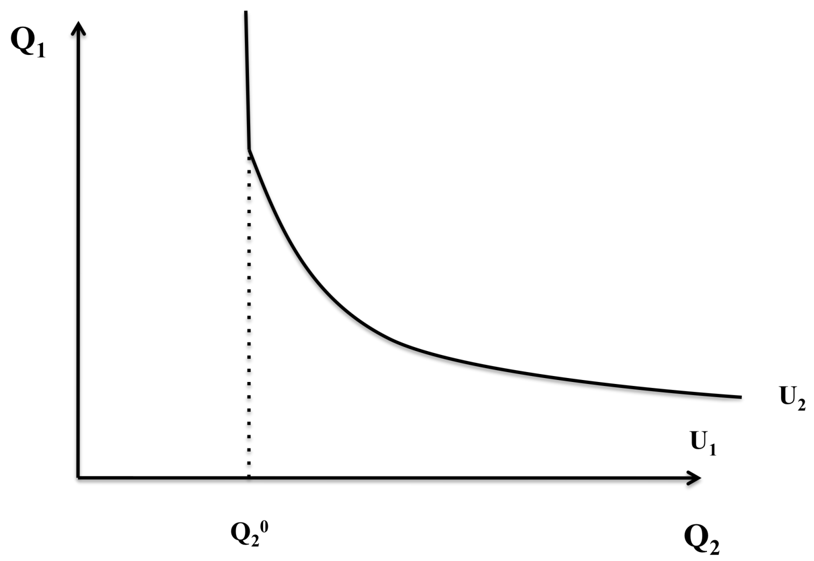


An obvious shortcoming of the substitutability assumption in the social indifference curves is that in some cases there may not be a reasonable substitute (e.g., endangered species or rare landscapes). We can illustrate this lack of substitutability through an alternatively shaped indifference curve. Figure 4 illustrates an indifference curve for

[22] Note that in special circumstances the damaged and restored environment might be the same, but represent two different time periods: the recovery period, followed by the fully restored period.

a society that is not willing to substitute indefinitely between a damaged environmental resource, Q_2, and a substitute remediated environmental resource, Q_1. That is, society is willing to accept the loss of Q_2 by receiving more Q_1, but only down to Q_2^0. In other words, adequate compensation - in the form of more Q_1 - is not possible if Q_2 drops below Q_2^0. Substitution is no longer acceptable. We may interpret Q_2^0, for example, as the minimum viable population of some species.

Figure 4 Individual indifference curve without substitution past Q_2^0



In the case of extremely rare landscapes or endangered species, resources may be considered un-substitutable (e.g. extinction of a rare species). There is no economically justifiable mechanism to address compensation for un-substitutable resources. In other words, without the substitutability assumption, the economic framework is no longer applicable. However, resource equivalency can still provide a useful framework for compensating for the loss of rare landscapes, endangered species, or other irreplaceable resources (which is legally required under the ELD), by making a distinction between irreplaceable and un-substitutable resources (Section 5 "Compensating for irreplaceable/unique resources").

4.2 Providing compensation: measures of loss and gain

Given an understanding of how welfare economics measures well-being (changes in utility) and how it measures preferences for alternative bundles of goods (indifference curves), the next step is to identify measures and mechanisms for providing economic compensation. To illustrate the issues, we address five key methodological questions below and discuss how equivalency analysis deviates in some respects.

4.2.1 Question #1: How should a negative impact on welfare be measured?

Impacts on human welfare are measured by changes in utility. That is, the relevant unit of measurement when comparing "human well-being" with X (damaged environment) to well-being with Y (restored environment) is utility.[23]

Because individuals' utility changes are not observable we need an indirect proxy to measure a welfare change. The most common is a money measure of utility change called Compensating Variation (or Equivalent Variation), which is addressed under Question #2. But EA is based on the notion that money measures of utility changes are objectionable. Thus, a REA and HEA make a strong assumption that we can proxy the utility change by assuming it moves proportionally with changes in an ecological metric. For example, a 50 percent decrease in the population of a key species would reflect a proportional drop in an individual's utility. Similarly, an equivalent increase over time of that species' population would lead to a utility increase that exactly offsets

[23] It is important to note that the legal requirement in the ELD ensures a focus on welfare losses due to resource loss and gain, exclusive of profit loss (e.g., producer surplus). Loss of profits that may accrue to businesses that rely on a resource or service (e.g., fishing tourism impacted by a chemical spill) is excluded from our concept of environmental compensation as it is addressed through alternative legal channels (e.g., tort law).

(or compensates) for the original loss. This is not so much a critique of the welfarism approach as it is a simplification for the purpose of meeting legal requirements for environmental compensation (The welfarism paradigm inherent in welfare economics assumes that all changes should be evaluated in terms of utility, or some type of value information (Berrens 2001). Welfarism is challenged most frequently when there is considerable uncertainty in measuring the effect of some change on utility, which is certainly the case with the assessment of environmental resources).

Thus, welfare economics suggests that the practical measurement of welfare changes should be based on money measures of utility changes, which a "value-to-value" VEA attempts to do. More interesting for this study is that a recourse-based equivalency approach (e.g., REA/HEA) violates this principle and instead assumes that the ecological changes measured in a non-monetary metric approximately mirror the change in value that individuals attach to the loss and gain of that resource or service.

4.2.2 Question #2: How do we quantify an adequate amount of compensation?

Given that compensation must be based on a utility change -- which itself is not measurable -- we need indirect and observable measures to help us estimate "how much is enough" compensation. Economics suggests the use of Compensating Variation[24] (CV) or Equivalent Variation (EV) as measures of compensation. However, a third measure related to resource quantity and quality -- described as R below -- also represents a valid measure of compensation.

Our goal is to define a welfare measure in terms of the underlying (observable) indirect utility function, as illustrated by the indifference curves in Figure 5. An individual is assumed to trade-off an amount of private goods, X, with an amount of public environmental goods, Q. Specifically at point A, the individual is assumed to have spent all of his/her income (M) on an amount of private goods (X=M) and selects the amount of costless public environmental good (Q_0) according to U_2.

[24] A common measure of how exogenous changes impact individuals' welfare is consumer surplus, which is useful in quantifying the utility change that may arise from a change in price or quantity of a "priced" good. But, in our case the quantity or quality of a non-priced environmental resource is being affected, which means consumer surplus cannot help us.

Our welfare measure assumes that the initial utility level is constant (U_0) and associated with the status quo - the right to an uncontaminated environment[25] (Q_0). Our measure must answer the following: given a reduction in Q, what is the appropriate amount of compensation for the individual to be indifferent between the initial clean environment and a contaminated one? The answer is Compensating Variation (CV) and is the theoretically-correct welfare measure. Thus, CV identified in Figure 5 would be sufficient to offset the interim loss (illustrated in Figure 1) and thus represents the correct magnitude of compensatory restoration[26] as described in Section 3.1.

The hypothetical question above is similar to asking an individual to accept an undesirable change (e.g. contaminated wetland) in exchange for some compensation payment. Therefore, it is also referred to as a person's "willingness to accept" compensation (WTA) for a deterioration of the environment.[27] An individual should be willing to accept an amount equivalent to the CV in order to be returned to his/her pre-contaminated level of utility. Figure 5 demonstrates this concept. Assume an individual is at point A on indifference curve U_2 and the quantity of the public good decreases due to damage from Q_0 to Q_1. For a given amount of a private good (x=M, indicating that all income, M, is spent on the private good), this causes the individual to fall from U_2 to U_1 (point B). The compensating amount in terms of private goods (or money, which can be used to buy private goods) that would be required to make this individual indifferent between the

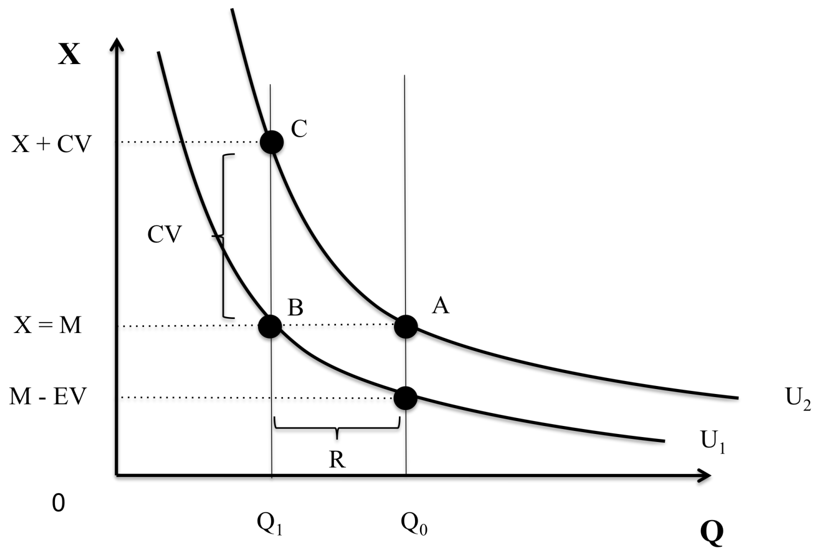
[25] Note this last qualification rules out the possibility of using the Equivalent Variation (EV) measure, because it assumes that the new utility level associated with Q1 (the contaminated wetland) is the basis of comparison and, instead, asks the question: "How much would an individual pay after the loss of the wetland to return to the original level of utility (with an uncontaminated wetland)?" Because we assume that the public has an inherent right to the level of utility associated with Q_0 (the uncontaminated wetland), we rely instead on CV.

[26] This assumes the damaged environment is returned to baseline. If it does not (i.e., long term damage), complementary restoration would be needed in addition to compensatory restoration.

[27] If, instead, the hypothetical question asked an individual to pay for a desired environmental improvement before it happened, it would be referred to as a "willingness to pay" (WTP), which is associated with the CV welfare measure (see footnote above). The reason is that CV is defined relative to the initial level of utility. The improvement increases utility and the payment equalizes utilities in the two states.

original and damaged environment is the compensating variation, or CV on the graph.

Figure 5 Compensating an individual for a reduction in the non-market public environmental good, Q



Therefore, CV is an appropriate money measure of compensatory restoration for environmental damage (either in terms of private goods or money). The size of CV is estimated through various types of economic valuation, where individuals are asked to state the amount of money (a monetary metric) they would require as compensation to ensure they remain on their original utility level. It can be represented as[28]:

$$u_1^0(q_1^0, q_2^0, y_i) = u_i^1(q_1^0 - \Delta_1, q_2^0, y_i + CV_i) \quad (1)$$

where q is a measure of environmental quality or services and y_i is income of individual *i*. The debit is measured by the reduction in services provided by q_1, by the quantity Δ_1. The individual is fully compensated by a payment of CV_i and the total value of the damage is the sum of compensating variation across all affected individuals (for

[28] Taken from Roach and Wade (2006)

simplicity, this equation does not incorporate discounting, see Question #5).

In addition to private goods or money (Y axis), another way of measuring the appropriate magnitude of compensation for environmental damage is the quantity of public environmental good, measured on the X axis. This is an equally appropriate measure of compensation because it too ensures in theory that an individual is "no worse off" in terms of utility than before the damage. The size of R can be estimated by asking individuals to state the amount of resources (a non-monetary metric) they would require as compensation to ensure they remain on their original utility level (Examples include Breffle and Rowe 2002; Molowny-Horas et al 2008). Theoretically, it can be represented as[29]:

$$u_1^0(q_1^0, q_2^0, y_i) = u_i^1(q_1^0 - \Delta_1, q_2^0 + \Delta_2, y_i) \qquad (2)$$

where a loss has occurred to q_1 and Δ_2 represents restoration to, q_2, which would ideally be similar in type and quality to the resource injured (q_1). Therefore, R is an appropriate resource measure of compensatory restoration for environmental damage.

There is one inherent characteristic of environmental resources that ensures that Δ_2 in formula (2) is necessarily greater than R in Figure 5: the discrepancy (delay) in providing resource compensation (see also Section 4.2.5). Figure 5 depicts a scenario that assumes that the damaged environment is immediately "given back" to the individual. If a resource is immediately given back (as in private compensation), an interim loss has not occurred and environmental compensation is not required ($\Delta_2 \sim 0$). A more likely scenario is that the environment takes years to recover to baseline, implying an interim loss that consists of annual losses of (no more than) R each year. Thus, R in Figure 5 is insufficient compensation because it does not account for the full interim loss (Jones and Pease 1997). One may think of R as primary restoration because it improves the quality/quantity of a damaged resource toward baseline. Thus, compensatory restoration is over and above R and -- in the case of primary restoration failing to return the environment to baseline conditions -- complementary restoration would also be required.

Two additional caveats to Figure 5: first, it does not incorporate society's positive time preference which says, all else equal, society

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[29] Taken from Roach and Wade (2006), which referred to Flores and Thacher (2002) and Unsworth and Bishop (1994).

prefers to consume today rather than wait (see Question #5); and second, even though resources (R) and money/private goods (CV) represent valid measures of compensation for individuals, legal requirements for environmental compensation (e.g., ELD) require that the actual provision of compensation be in the form of R (see Question #4).

Table 3 summarizes the appropriate measures of compensation for loss as discussed above. Importantly, both monetary and non-monetary metrics are valid measures of compensation.

Table 3 Comparison of compensating welfare measures for resource compensation

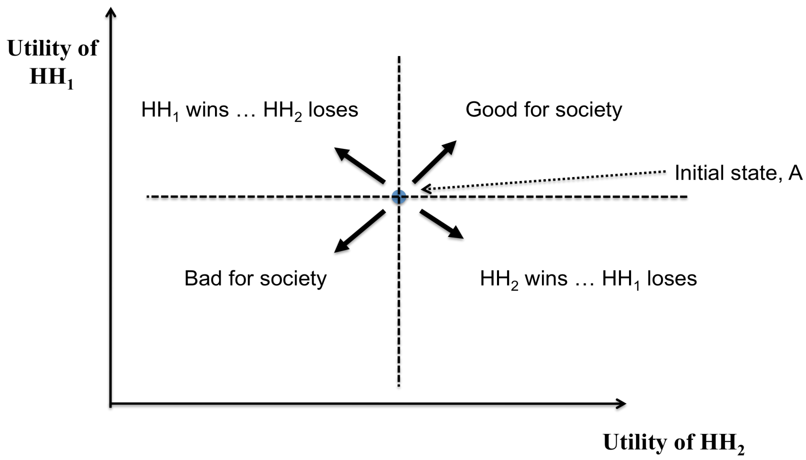
Compensating measure	Basis for well-being measurement	Method for obtaining measure	Stated Preference scenario
CV - (Y axis in Figure 5) [see formula (1)]	utility	Stated preference survey with monetary metric	How much compensation would you be willing to accept in terms of *money* to return to the original (pre-damage) utility level?
Δ_2 - (X axis in Figure 5) where R < Δ_2) [see formula (2)]	utility	Stated preference survey with monetary metric	How much compensation would you be willing to accept in terms of *resources* to return to the original (pre-damage) utility level?[a]
[a] The HEA/REA approach obviates the need for a stated preference survey and instead assumes that society is willing to trade-off the value of a damaged resource with a restored resource in proportion to change in the non-monetary metric (e.g., acres).			

4.2.3 Question #3: How do we aggregate individual preferences?

So far we have only discussed how to compensate on an individual level, but our ultimate objective is to compensate society. Aggregating the results obtained thus far raises a number of difficult issues. Below we will identify these and then identify the implicit and simplifying assumptions that apply in the case of REA and HEA.

The problem arises when some individuals' preferences are such that they gain from a proposed restoration project, while others may lose (there are also examples of relative winners and losers from assessing the damage). When a 'project' leads to both winners and losers in society, the question arises: whose preferences should determine the social ranking of the project? In other words, how do we (or should we) weight individual preferences when they differ? The answer to such a question is inevitably subjective, yet welfare economics can at least inform the discussion.

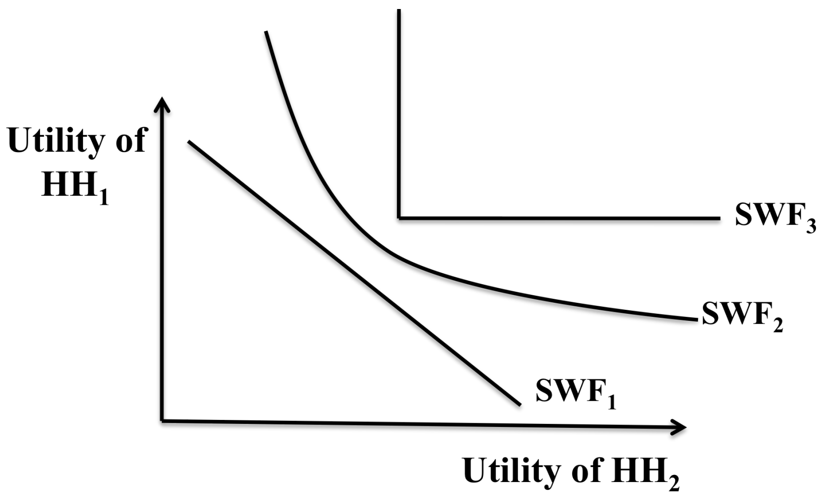
Figure 6 Alternative social states, or outcomes, from a proposed policy action (based on Johansson (1991), Figure 2.1).



Welfare economists often cite two criteria for aggregating preferences: the pareto and compensation principles. Figure 6 illustrates how a 'social planner' might consider the trade-off in utility between two individuals when deciding whether to proceed with a (e.g., restoration) project. The Pareto principle suggests that projects should be undertaken as long as everybody is made better off, or at least nobody is made worse off (moving northeast in Figure 6). But such a criteria cannot handle cases of winners and losers (i.e., going northwest and southeast). The compensation criteria (also referred to as the Kaldor-Hicks criterion) attempts to rectify this problem and suggests that a project should be undertaken so long as the winners can hypothetically compensate the losers and everybody is still better off. Compensation in this case refers to the redistribution of the (presumably inequitable) allocation of income that resulted from a given project. It is a less than ideal criteria because it makes an a priori assumption that the utility of each individual in society is valued evenly (i.e., it cannot compare how much the losers 'lose' and how much the winners 'win,' in order to decide whether a project has net social benefits). This is, in part, due to our assumed ordinal utility functions, which preclude a unique, meaningful and comparable 'utility score' across individuals.

A more ideal, though not so practical, criterion is to rely on a Social Welfare Function (SWF) to aggregate individual preferences. A SWF represents, at least in theory, a complete and consistent ranking of social projects because the shape of the curves in Figure 7 implicitly evaluates the trade-off in utility between household 1 (HH_1) and household 2 (HH_2). For example, if a restoration project stands to benefit HH1 to a greater extent than HH2, the social planner could simply consult the relevant SWF, which identifies how society weights the utility of individual households, and then decide whether the project results in net social benefits or not. The major drawback is, of course, that it requires normative input (ethical judgment) from society's decision-makers to determine the shape of the SWFs. Thus, welfare economics tends to avoid the controversy surrounding weights by falling back to the assumption inherent in the Kaldor-Hicks compensation principle: each and every person's utility is valued equally, as shown by SWF_1. (note that even this decision -- that each household's utility change should be weighted equally -- involves an ethical judgment).

Figure 7 Alternative Social Welfare Functions (SWF)



Caption to Figure 7: SWF_1 represents an egalitarian or utilitarian shape, which is most commonly assumed (though not necessary) form in practical application such as a CBA and has a slope of 1. SWF_2 represents a progressive form, which weights the utility change of the "utility poor" higher than the utility change of the "utility rich." Finally, SWF_3 represents a Rawlsian form which argues that the welfare of society is a function only of the worst off households (i.e., society gains nothing from projects that increase the utility of the well-off).

Note the similarity with Figure 3, which shows how society as a whole is willing to trade-off damaged with restored resources. Figure 3 assumes that preferences have been aggregated based on some criteria and ethical judgment, which allowed for a social trade-off between specific goods (environmental resources) to be made. Figure 7 represents a discussion of how to make that aggregation in the first place.

Thus, welfare economics suggests that aggregation of individual preferences inevitably involves ethical judgments. For lack of socially-acceptable methods for estimating household weights the default assumption in CBA is most commonly an egalitarian one[30], as shown by SWF_1 in Figure 7. In the case of REA and HEA, we are implicitly assuming that (1) utility moves proportionately with the non-monetary metric and (2) this proxied utility per household is traded-off evenly just as it is in the case of a CBA. But, as discussed in Section 5, a number of other complications arise because of the nature of resources themselves (i.e., the non-divisibility characteristic of public goods).

4.2.4 Question #4: What is a valid compensation mechanism?

A compensation mechanism is the good provided to an individual (or in our case society) in lieu of his/her first choice. As shown in Figure 5, either private goods/money (Y axis) or an amount of public goods (X axis) represent reasonable compensation mechanisms from a welfare economic perspective. However, for purely legal reasons, the

[30] Again, it is not a necessary requirement to conduct a CBA. Kanninen and Kriström (1993) showed how the results of a CBA may change depending upon the slope of the assumed social welfare function.

compensation mechanism in the case of environmental compensation must be in the form of environmental resources or services.[31]

As long as individuals are willing to trade-off the consumption of one good for another, as illustrated through indifference curves like those in Figure 2, then alternative compensation mechanism may also fulfill the requirements for 'economic compensation.' For example, Lazaro-Touza and Atkinson (2009) conducted a survey to assess the willingness of individuals to trade-off environmental damage from an oil spill with three types of social improvements: (1) man-made capital infrastructure (roads), (2) social capital (schools, hospitals), and (3) natural capital (environmental compensation projects). They found that across three hypothetical oil spill sizes (small, medium, and large), individuals preferred social capital to natural capital at an almost 2 to 1 ratio. This would seem to support the speculations of Turner (2007) that money may not compensate for certain environmental losses.

The above result notwithstanding, welfare economics suggests that the most appropriate compensation mechanism is money because, in theory, it is divisible and can be provided in different amounts to different individuals to exactly compensate their loss. Flores and Thatcher (2002) argued that money was the only theoretically pure compensation mechanism for environmental damage. For example, following contamination of a popular sports fishing lake, a fishermen could be provided additional financial compensation to offset his/her presumably larger utility loss, as compared to a non-fishermen. This is not the case when the compensation mechanism is a non-rival and non-exclusive public good because "... no one can be excluded from the benefits [of consumption] and additional consumers may use it at virtually zero marginal costs" (Johansson 1991, p. 63-64).

However, the discussion of monetary compensation mechanisms is somewhat academic because legal requirements ensure that compensation is resource-based (although the measure of loss and gain may be measured with or without money). This requirement leads to several implications discussed in Section 5.

[31] The ELD Annex II 1(d) notes that an interim loss " ... does not consist of financial compensation to members of the public" (see also Randall 1997).

4.2.5 Question #5: How do we account for time ?

In compensating individuals for private loss the underlying assumption is that the compensation mechanism (usually money) is provided immediately. This is not the case with environmental compensation because of the dynamic nature of debits and credits.

Time affects an EA in two ways. First, the debit and credit may occur at different times ("time discrepancy"). Most frequently (but not always) the damage occurs relatively close to the present while the compensation gains occur further into the, as shown in Figure 1. The main reason is that restoration projects take time to mature (e.g., a planted tree or an enhanced wetland provides ecosystem services gradually over time. Debits also follow a gradual pattern of decreasing loss (recovery) over time). Second, debits and/or credits may occur extremely far into the future, which demands contemplation about how the current generation (the decision-makers) should weigh the (uncertain) impacts on future generations, when these generations are not able to express their preferences today.[32] Thus, the question arises, can we apply some quantitative measure to adjust for impacts occurring at different times so that we can compare them? If so, how do we establish a weighting system?

The weighting system used in EA (and CBA) is based upon a positive discount rate, which implies a reduced value for impacts (both debits and credits) occurring in the future (discounted) and an increased value for impacts occurring in the past (compounded). In other words, resource flows are considered analogous to financial annuities, which provide an output over time that is adjusted to reflect an individual's positive time preference. Because this raises several issues, we will examine this in greater depth, in particular:

- Practical calculations of discounting in EA
- Economic justification for discounting consumption (our numeraire)
- Economic justification for discounting resource units
- Identifying an appropriate discount rate

[32] There are several environmental parallels to this problem: biodiversity protection, endangered species protection, climate change impacts, storage of radioactive waste, thinning of the ozone layer, persistent groundwater pollution, minerals depletion, etc. See Weitzman (1998). A further list of references can be found in Nordhaus (1994); and Layton and Levine (2003).

4.2.5.1 Practical calculations of discounting in EA

Table 4 and Table 5 illustrate in practical terms the discounting of a non-monetary metric (hectares) for a hypothetical debit and credit calculation in an HEA.[33] The focus here is less on the underlying assumptions and more on the practical calculations. We assume the following:

- Damage to a wetland contaminated 50 hectares which precluded the provision of habitat services beginning in 2007 (e.g., flood control, water purification, habitat for species, etc). We assume a constant 100 percent service loss each year for 10 years, followed by "instantaneous" recovery in 2017 (Table 4);
- A restoration project provides 100 percent gain in habitat services above a pre-restoration baseline per hectare restored, starting in 2010 and lasting for 100 years (Table 5);
- As with an HEA, the hectares of contaminated and restored wetland (our non-monetary metric) is assumed to reflect a proxy for the effect of this ecological loss and gain on society's welfare and is, of course, the same on the debit and credit side; and
- A 4% discount rate; base year of analysis is 2010 (analysis conducted three years after damage was discovered). We discuss appropriate discount rates in Section 4.2.5.4.

[33] One could replace hectares with fish or birds to obtain an REA, with no loss in meaning.

Table 4 Illustration present value debit calculation using a four percent discount rate

	Baseline		Post-incident		
Year	Service hectare-years (Nominal)	Discounted service hectare-years (Present value)	Service hectare-years (Nominal)	Discounted service hectare-years (Present value)	Service hectare-years lost "Debit" (Present value)
	(a)	(b) = (a) * df[1]	(c)	(d) = (c) * df[1]	(e) = (b) - (d)
2007	50.0	56.2	0.0	0.0	56.2
2008	50.0	54.1	0.0	0.0	54.1
2009	50.0	52.0	0.0	0.0	52.0
2010	50.0	50.0	0.0	0.0	50.0
2011	50.0	48.1	0.0	0.0	48.1
2012	50.0	46.2	0.0	0.0	46.2
2013	50.0	44.4	0.0	0.0	44.4
2014	50.0	42.7	0.0	0.0	42.7
2015	50.0	41.1	0.0	0.0	41.1
2016	50.0	39.5	0.0	0.0	39.5
Total	**500.0**	**474.4**	**0.0**	**0.0**	**474.4**

[1] df = discount factor, based on the discounting formula: annual loss = nominal loss * (1+r)^(base yr - current yr) where r = 4% and base year = 2010

Table 5 Illustration present value per unit credit calculations using a four percent discount rate		
Year	Percent service gain per hectare (Nominal)	Discounted percent service gain per hectare (present value)
	(a)	(b) = (a) * df[2]
2010	1.00[1]	1.00
2011	1.00	0.96
2012	1.00	0.92
2013	1.00	0.89
2014	1.00	0.85
...	...	...
2060	1.00	0.14
...	...	...
2110	1.00	0.02
Total (100 years)		**25.49**

[1] 1.00 is the decimal form of 100 percent

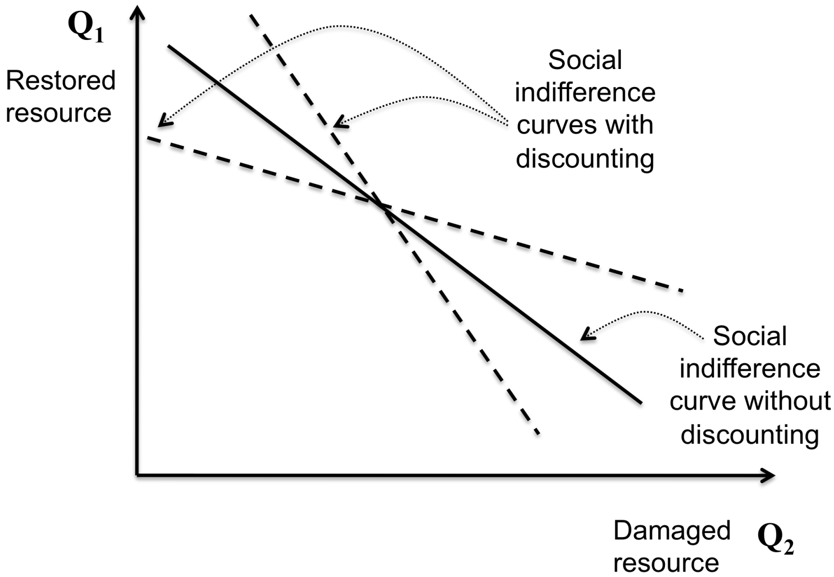
[2] see footnote Table 4

A total debit of approximately 474 discounted service hectare years (DSHaYs) occurred over 10 years and a per unit gain of approximately 25 DSHaYs per hectare of wetland restored can be realized through an environmental project. Therefore, equivalence between debit and credit over time requires approximately 19 (474/25=19) hectares of wetland restoration in the base year (today), which assumes these hectares will continue to provide annual gains over the project's 100 year time horizon. A number of observations can be made regarding the discount rate and time horizon:

- Holding all else equal, higher discount rates will:
  - increase the present value of debits accruing prior to the base year due to compounding;
  - reduce the present value of debits accruing after the base year due to discounting;
  - reduce (discount) the present value of credits due to discounting. This is always the case because restoration occurs after the base year (after an HEA/REA is complete).

- Scaled restoration (total debits / per unit credits) may increase or decrease with higher discount rates. That is, a sensitivity analysis of alternative discount rates depends as much on the time horizons of the debit and credit calculations as it does on the assumed discount rate. This is discussed below in conjunction with Figure 9.
- In general, alternative discount rate assumptions will lead to a large impact on an HEA's output (scaled restoration) if the impacts accrue far into the past or far into the future, relative to the base year.

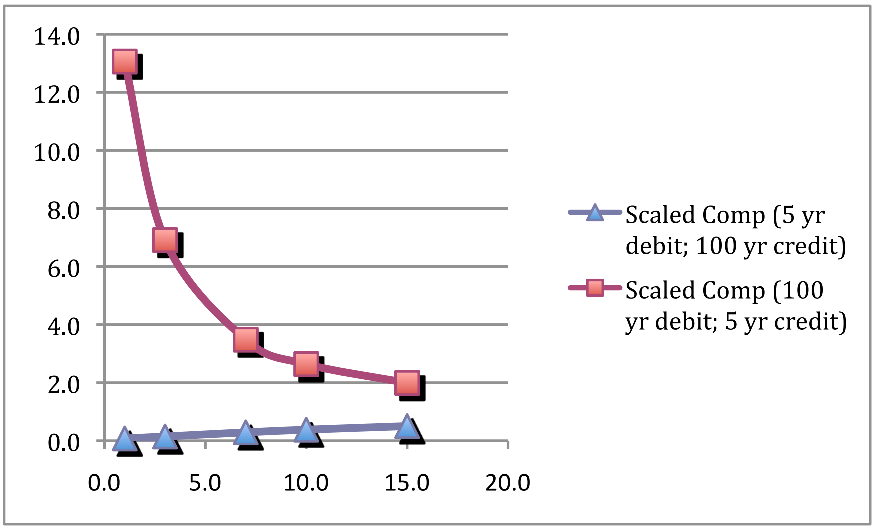
Figure 8 Illustrating the effect of discounting on society's resource trade-off (holding



social preferences constant across quantities)

The effect of discounting can be illustrated in Figure 8 in the context of society's implicit trade-off in an equivalency analysis. It is a simplified version of Figure 3 that assumes society's willingness to trade-off between damaged and restored resources is independent of scope. It demonstrates that alternative assumptions about the discount rate will alter the slope of the social indifference curve, but a priori we cannot predict whether the slope will increase or decrease. Figure 9 demonstrates that when the time horizon for the debit far exceeds the time horizon for the credit, increasing the discount rate will decrease the scaled compensation (squares). In contrast, when the time horizon for the credit far exceeds the time horizon for the debit, increasing the discount rate will increase the scaled compensation (triangles). The example is based on a simple REA using number of fish as the non-monetary metric, where 10 fish are assumed lost per year (debit) and restoration leads to 10 fish gained per year per mile of stream restored (per unit credit). Varying the discount rate (X axis) and the time at which the debit and credit impacts occur results in alternative scaling outcomes measured on the Y axis (where scaled compensation = 10 fish lost / 10 fish gained per unit of restoration).

Figure 9 Effect of alternative discount rate assumptions on scaled amount of compensation (Y axis --> number of fish restored per year; X axis --> discount rate)



4.2.5.2 *Economic justification for discounting consumption*[34]

Welfare economics identifies one key reason why an individual may discount a good or service that has economic value:[35] impatience (also referred to as a positive time preference). All things equal, an individual prefers to consume a good today rather than wait because he/she has a limited life span and may not be alive in 50 years to enjoy that consumption. This impatience can be called an individual's utility

[34] Some of this text is based on Cole and Kriström (2008)

[35] By economic value we mean the inherent worth that an individual (or society) places on an object. Value is affected by scarcity, substitutes, and time, among other things.

discount rate for consumption (our numeraire[36]). This impatience implies that an individual will only postpone consumption if he/she receives financial compensation from doing so, i.e., lending money, instead of consuming it, provides compensation in the form of an interest payment.

The reasons why a long-lived society may discount requires some additional considerations, some of which are ethical. The social discounting question is: what is the motivation for our generation to say that the value of social impacts that accrue to those alive in 100 years is not 1 unit (as it is in our generation) but perhaps something less? Below we highlight some possible motivations and link these together into a formula for estimating a social discount rate.

The first possible reason to justify social discounting is impatience. As with an individual, there is the possibility, however small, of future social collapse or catastrophe. However, this is controversial because it is not immediately clear why a supposedly infinitely-lived 'society' may be impatient. Philosophers have long argued that a positive social discount rate for general well-being is not ethically defensible because it discriminates against future generations -- by implying that their consumption is worth less -- just because they are not present today (Dasgupta, 2008) (But note this does not consider the potential for economic growth, as discussed below). There is some disagreement about the size of the (social) utility discount rate, though most believe that the number should be a small positive number, i.e., society exhibits some impatience represented by a small pure rate of time preference.[37] In formula (3) this is represented by δ.

A second reason for discounting may be that in a productive economy the marginal product of x will be greater in the future, thus endowing future generations with more consumption that we are capable of today. In other words, because we invest money today (do not consume) the next generation will be able to produce more goods (or improve the quality of goods) and will be able to consume more. If they are destined to be wealthier, then we have a moral right to discount to ensure equity in per capita incomes over time. There is

[36] Note that implicitly we are measuring well-being by the ability to consume, where greater consumption is assumed preferable to less consumption. In economic terms, "consumption" is our numeraire.

[37] For reference, various analyses assume a utility discount rate ranging from 0.1 percent per year (Stern 2006), to three percent (Nordhaus, 1994). A survey of economists by Weitzman (2001) estimates two percent per year.

little controversy regarding this "growth" motivation for social discounting, although the value of this parameter -- G in formula (3) -- evokes disagreement. If this parameter is two percent (as the growth rate in consumption has generally been in recent times), then those living in 100 years from now will be about six times “richer” than we are now.

The third reason for discounting future impacts that is often put forth by economists is based on the idea that future generations "may" value increases/decreases in consumption for the rich and the poor differently than how we value consumption changes for the rich and the poor today. This is referred to as an index of inequality. This parallels the discussion about social welfare functions and the inter-generational equity issue above in that it requires ethical judgment to determine a value for the parameter (η in formula (3)). Higher values reflect higher aversion to inequality and thus increases our estimate of the discount rate, all other things equal.

The so-called Keynes-Ramsey formula summarizes these motivations for a positive social (not individual) discount rate (r) and each parameter reflects our subjective assumptions about how to view social well-being. This version excludes population growth.

Social discount rate (r) = $\delta + (\eta * G)$ (3)

r = social discount rate to discount future impacts in society

δ = utility discount rate, an index measuring society’s impatience

G = Growth rate in numeraire (consumption)

η = Equity factor, an index measuring inequality

Those who argue for a zero social discount rate require at least two strong assumptions: (1) economic growth is zero over the long term (G=0)[38] or a normative assumption that consumption improvements for the poor are the only ones worth having (η=0); and (2) the social utility discount rate is zero for ethical reasons, i.e., it is unfair to consider future generation's consumption inferior to our own. Because virtually no economist is willing to make these strong (and normative) assumptions, social discounting of future consumption (based on utility changes) is an important part of evaluating impacts that occur over time.

[38] If economic slow down was fast enough, one could argue that future consumption is worth more, not less, i.e., a negative discount rate

4.2.5.3 Economic justification for discounting resource-units

The practice of discounting resource units can be motivated by the same factors -- impatience, economic growth, and inequality concerns. Moreover, applying a positive discount rate to resource units generally leads to logical and defensible outcomes for environmental compensation. There are, however, some special economic and ecological implications of discounting resources units directly, which we discuss in Section 5.

Several ecological publications have identified the challenge presented by the dynamic nature of environmental compensation (Norton 2008; ten Kate 2005; McKenney 2005) and some have suggested the use of discounting to address the time discrepancy (Moilanen et al 2008; Carpenter et al 2007; Morris et al 2006). Equivalency analysis -- developed incidentally by resource economists -- addresses the time discrepancy problem through a (subjective) weight reflecting the public's positive time preferences for resource consumption (an additional weight could be included to reflect uncertainty). Let us examine the motivations and implications behind the social discounting of resource units.

Impatience (δ). Social discounting of resource units can be motivated by society's uncertainty about whether "it" will be around in the future to consume resources -- either those that are damaged or restored. That is, a catastrophic event may prevent 'society' from being present to consume that resource, indicating a positive pure rate of time preference. To the extent that there is uncertainty regarding ecological estimation,[39] an additional component of uncertainty could theoretically be added to the pure rate of time preference (δ) to reflect a higher discount rate -- assuming such information is available for use in a stochastic model. As noted above, EA relies instead on a deterministic approach.

Growing economy (G). We can also justify social discounting of resources on the grounds of economic growth. Consider investment in both physical and natural capital. Investment allows future generations to either (1) better substitute private capital for natural capital, referred to as weak sustainability (e.g., provide ecosystem services through technology, such as flood control through dam construction) or (2) improve environmental restoration technology, a

[39] For example, uncertainty pervades both the debit and credit estimations because ecological projections of future losses and gains in a metric are our best guess.

mechanism to achieve strong sustainability (e.g., improve our ability to enhance ecosystems or to prevent declines in species populations). Thus, if we assume a growing economy with productive investment (e.g., research into the knowledge of ecological restoration) we will ensure more of both physical and natural capital for future generations, enabling us to discount their consumption.

Inequality (η). As above, this parameter requires a normative assumption about whose consumption within a generation is more important. While this parameter is relevant in this context, it is impossible to motivate a particular value based on objective reasoning.

Consider the belief that we may improve our ability to restore environments in the future when the science of restoration ecology advances and matures (G increases). All else equal, this would increase our assumed social discount rate, r, according to the formula. The implication is that resource consumption by future generations is less important (they will be better equipped to deal with environmental damage) and our consumption of resources today takes priority. Thus, the formula above reflects our implicit judgment that societal well-being requires more restoration today when the future looks bright (leading to a higher r), compared to a situation where the future looks bleak (leading to a lower r), all else equal. Note this would hold true even if society as a whole were infinitely patient (δ=0) and believed, on ethical grounds, that we should not discriminate against future generations' consumption of resources.

A zero discount rate requires strong assumptions and leads to counter-intuitive outcomes. When 'r' equals zero society values a hectare of wetland today the same as a hectare of wetland in 100 years, which leads to a strange outcome: society is indifferent between Plan A that restores X hectares today and Plan B that restores X hectares in 100 years. In this case a responsible polluter could, in theory, delay restoration indefinitely and welfare losses would never be compensated. In contrast, restoration projects that provide immediate annual gains (rather than far into the future) require less total restoration over the project life, which means that a positive 'r' gives a financial incentive for the polluter to select projects that maximum the present value of resource flows.

A zero percent discount rate also makes equivalency impossible when environmental damage or gains are perpetual. Imagine for example, an oil spill that has destroyed a wetland with no hope for recovery in the future. Quantifying the debit with a metric (monetary or otherwise) is impossible with a zero discount rate. The implication is that such damage is infinite and finite compensation cannot be scaled. Thus, the equivalency analysis framework breaks down.[40] In contrast, a positive discount rate allows the calculation of perpetual damage using a simple perpetual annuity formula (annual loss = total loss/discount rate). Perpetual gains from a restoration project can be quantified in a similar way, ensuring finite scaling.

In summary, the use of a non-zero discount rate is logically motivated based on society's time preferences. Discounting within an EA addresses the time discrepancy problem by weighting the value of these impacts (based on society's pure time preferences) to ensure they can be compared. In this way discounting provides a standardization of resource units to ensure the public can verify "equivalence" between (present value of) debits and (present value of) credits. Discounting can also incorporate additional concerns about uncertainty in the projection of future ecological change (assuming information was available for use in a stochastic model). Finally, a positive non-zero discount rate creates incentives for polluters to provide timely restoration projects that focus on providing immediate resource flows, thus ensuring compensation for welfare impacts that accrue over time.

4.2.5.4 Identifying an appropriate discount rate

Because the choice of discount rate has a significant effect on the scaled amount of compensation, one may ask the question: what is an appropriate rate for quantifying debits and credits? Weitzman (2001) surveyed 2,160 economists on the topic of which discount rate to use in a CBA and found that 98% of economists agreed that a positive discount rate for future impacts was warranted. However, as noted in Layton and Levine (2003), "... the agreement ends there." (p. 534). This is inherently a subjective decision, but a discussion of the literature does provide some guidance.

The general practice of discounting in equivalency analysis in the US is based on guidance from the US government, which suggests a seven percent rate, with a sensitivity analysis using three percent (NOAA, 1999). The REMEDE Toolkit (Lipton et al 2008) advises that individual Member States refer to national guidance. Table 6 provides a summary of some relevant guidance.

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[40] If the damage is not perpetual, then the debit can be scaled using a zero discount rate, but as noted above this creates disincentives for timely restoration.

Table 6 Country guidance on social discount rates to use in CBA or other long-term project assessment

Suggested Discount rate	Relevant publication	Source
declining discount rate 3.5 % for years 1-30; 3 % for years 31-75; 2.5 % for years 76-125; 2 % for years 126-200; 1.5 % for years 201-300, 1% for years 301+	UK Guidance (Green Book)	HM Treasury (2003)
4%	Unofficial guidance from Spain	Reira (2007)
4% (with sensitivity analysis at 2%)	Swedish Environmental Protection Agency and Swedish Institute for Transport and Communication	Swedish EPA (2003); SIKA 2002
4%	European Union guidance on assessment of regulatory impacts of EU Directives	EC (2005)
7% (with sensitivity analysis at 3%)	US Office of Management and Budget (White House)	US OMB (2003)
3%	US National Oceanic and Atmospheric Administration guidance related specifically to assessing environmental damage and compensation	NOAA (1999)
4% (higher rates for riskier projects)	Norway Department of Finance	Finansdepartamentet (2005)

These guidance documents in Table 6 generally provide an estimate of society's pure social rate of time preference, or utility discount rate (δ in formula (3)). For example, in the US the seven percent rate was based on measures of productivity growth or the after tax real return of interest, where both gave similar results (NOAA, 1999). Rather than using economic theory, Weitzman's survey suggests an "expert panel" approach, which concluded that society should use a rate of 4 percent in the immediate future (5 years), declining to around 0 over the long-term (300 years). In yet another approach, Layton and Levine (2003) use empirical data from a survey of the public to ask about their social time preferences for mitigating climate change impacts. They conclude that the public implicitly discounts the future at a rate of just under 1 percent annually. In an empirical study more relevant to the case of environmental compensation, Breffle and Rowe (2002) conducted a survey that varied the time at which PCB contamination remains in the environment and concluded that the public did, in fact, exhibit positive time preferences for consumption of resources on the grounds of impatience.

Because the impact of constant discounting becomes increasingly severe over time (exponential), it can have a seemingly disproportionate impact over long time periods. This has caused some to show caution in using the discounting tool for comparing values across extremely long time horizons. For example, many economists have pointed out that long-term environmental problems have stretched the boundaries for which CBA was originally intended -- "a single generation borrowing from itself" (Krutilla and Smith 1988). In the case of climate change -- and in cases of persistent environmental damage -- projects are stretching several generations. This has led to an alternative approach called hyperbolic discounting, where a constant discount rate is replaced by one that declines over time (Weitzman 2001; see also UK rate in Table 6). Some economists have argued that this may better reflect how the current generation actually compares their consumption to that of future generation's across extremely long time horizons (Weitzman, 2001).

Importantly, these estimates of pure social time preference suggested for use in assessing long-term environmental impacts (including the proposed hyperbolic rate) do not explicitly incorporate uncertainty (Hampton and Zafonte, 2004). Including uncertainty about restoration project success would entail incorporating the odds of project failure into the discount rate which would, all else equal, increase the discount rate. Hampton and Zafonte (2004) showed that in some cases, this may overwhelm the effect of time preference on restoration scaling. For example, the authors show that incorporating an annual 1-in-100 chance of project failure into a three percent discount rate can lower the present value (and amount of restoration credit) by 18 percent in one of their scenarios. However, our deterministic approach assumes a priori that information about the possible variance around the mean outcome (e.g., likelihood of restoration success) is not available and thus (equivalency analysis) handles uncertainty through an ex post sensitivity analysis.

Ecological publications have suggested the use of discounting to deal with the time discrepancy issue, but their conclusions differ. Carpenter et al (2006) prefer low discounting of future benefits in order to "green" conventional CBA, as this assigns more substantial weight to ecological benefits that come on line slowly. But this focuses rather narrowly on the benefit side. Moilanen et al (2008) focus more broadly on both sides of the equation by examining compensation ratios (i.e.,. ratio of compensatory gain to environmental loss) and suggest that a time discounted weighted average is important in environmental compensation schemes because loss tends to be up-front, while gains tend to occur far into the future. They demonstrate that increasing discount rates lead to greater amounts of compensation. But this conclusion includes a priori assumptions about the time horizons of the losses and gains. The authors' conclusion suggest that ecologists would be prudent to use discount rates that are not too low, thus ensuring sufficient compensation ratios (where 'sufficient' is defined in ecological terms).

In summary, should we employ a relatively lower or higher discount rate for long-term environmental compensation schemes? As I show in Figure 9, one cannot select a discount rate based on an a priori belief about how diligent society should be in protecting resources or achieving (strong) sustainability goals. Instead, the social discount rate should be based first and foremost on society's pure time preferences as it relates to resource consumption and, secondarily, may consider the implication of restoration project failure (which, all else equal, would increase the discount rate). For debit or credit calculations that last long into the future, special consideration should be given to the possibility of using declining, rather than constant, discount rates as suggested by Weitzman (2001). That is, a moderate discount rate in the near future would give incentives for timely restoration, but lower discount rates in the far future may better reflect assumptions about how we view future generations' consumption. Other factors in selecting a discount rate require normative assumptions about how we view the consumption possibilities of certain members of society or require uncertain projections regarding future economic growth.

4.2.6 Conclusions - measuring and providing compensation

Environmental compensation is based on the concept of substitutability, i.e., that society as a whole can be compensated for the loss of an environmental resource or service by the provision of an alternative resource or service that is restored, re-habilitated, or replaced. In summary:

- Welfare economists suggests that a monetary measure of utility change is the only valid way of measuring changes in human welfare and the use of non-monetary metric necessarily involves a strong assumption that utility changes are proportional to changes in the ecological metric, and therefore is a less preferred measure of welfare.
- However, as shown in Figure 5 both monetary (CV) and non-monetary (R) metrics represent valid measures of the magnitude of compensation required to ensure an individual is just as well off as he/she was before a damage occurred. However, the caveat when using a non-monetary metric is that R is not sufficient compensation because it does not account for the interim loss that occurs over time.
- Aggregation of individual preferences (which form the foundation of welfare economics) to the societal level necessarily involves several ethical judgments. The default assumption in CBA -- and equivalency analysis -- is an egalitarian approach which simply sums the utilities of individuals under the implicit assumption that each person's change in utility is equally valued by society (SWF_1 in Figure 7).
- The actual compensation mechanism is driven by the legal requirement in the ELD that society must receive restored, rehabilitated or replaced resources in lieu of their first choice (undamaged resources).
- Discounting solves one of the dilemmas when providing environmental compensation -- the fact that the debits and credits occur at different times. The basis for using a discount factor to weight the value of impacts according to "present value" is well-established, although the specific value of this weight attracts disagreement due to the extraordinary effect the discount rate can have on the conclusion of long-term assessments. By not using a discount factor, we are implicitly assuming that society is infinitely patient and can wait for restoration to occur. Plenty of evidence exists to contradict this assumption. From a practical matter, a discount rate helps when calculating impacts from perpetual damage.

- While welfare economic tools can help, inevitably ethical judgments are required if we want to evaluate society's well-being. The most obvious normative issues involve aggregating individual welfare changes within the current generation (social welfare function) and considering the welfare changes across generations (discounting, in particular η and δ from Equation 3). They are based on comparing the inherent well-being of different generations in an effort to maintain the same level of well-being over time. In other words, these motivations are, at the core, ethical arguments detailing how the current generation should care for, and make decisions for, the future generation.

5 Implications: Environmental compensation using REA/HEA

This section summarizes the main findings and implications that arise from applying the welfare economic principles of compensation to the case of environmental compensation scaled using REA and HEA.

Economic compensation -- on which environmental compensation is based -- assumes that negative welfare impacts can be offset by providing individuals (or society) with a substitute good in lieu of their first choice. The scaling of restored resources in lieu of damaged resources using a non-monetary metric is a relatively new concept in Europe. While it avoids the difficulties of informing the public about the consequences of ecological change -- such that they can estimate how it affects their utility through monetary valuation -- it, instead, places a high burden on the interdisciplinary team conducting an environmental compensation assessment because their selection of an ecologic metric has significant consequences for the final compensation outcome. That is, HEA/REA shifts the burden of estimating welfare impacts from supposedly 'informed members of the public' (as with monetary metrics in a VEA approach) to natural and social science experts.

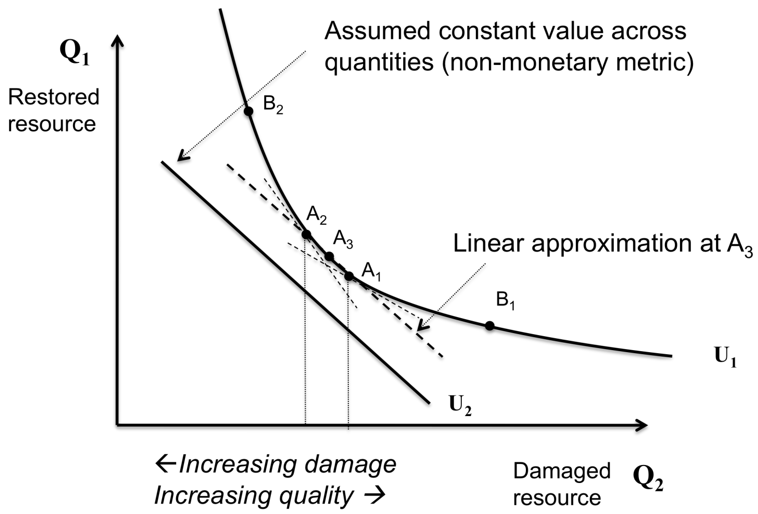
Below we provide a summary of the key economic and policy implications of scaling environmental compensation using HEA/REA. When discussing implications of EA *in general* (i.e., including VEA) I refer to "EA." However, when referring to the implications of non-monetary metrics specifically, I refer to REA/HEA.

- **Environmental compensation is an anthropocentric idea**. Environmental compensation is a human-centric idea that focuses on offsetting welfare impacts to the public. Indeed, the concept of sustainability is anthropocentric in that it suggests that we can maintain the health of physical (weak sustainability) and natural (strong sustainability) capital for use by future generations. The practice of discounting in EA is an inherently human-centric idea, as it assumes that society itself is inherently impatient when it comes to consuming public environmental goods. In short, environmental compensation is not for the birds; it is for society.

- **Interdisciplinary**. The measurement of ecological change -- a key input to an environmental compensation assessment -- and the measurement of human well-being (welfare) is indisputably connected (English et al 2009). For example, we cannot assess the impact of environmental damage on an individual's well-being without first trying to explain the expected decline in ecosystem services, usually with reference to a baseline condition or other ecological factors. Similarly, we cannot assess individual well-being associated with alternative *compensatory/complementary restoration* without relying upon the language of ecology to explain the attributes and expected outcomes of proposed projects. Thus, ensuring appropriate compensation for resource loss requires a merging of ecological measurement with the theories of welfare economics (this applies, of course, to the EA framework in general).
- **Social indifference curves and constant value across quantities**. In the theoretical economic framework, the amount of compensation for an environmental loss is based on social indifference curves, which measure a constant level of social utility. An HEA/REA does not rely on the utility approach and instead uses a non-monetary metric to measure environmental loss and gain, which generally assumes a constant relationship between the physical environmental change (e.g., acres lost/gain) and the value society places on that change. Relying directly on this ecological unit change rather than filtering the effect of this change through an indifference curve that reflects social preferences runs the risk of wrongly assuming a linear approximation over an entire interval (e.g. restoration project). As explained below, this may be a problem when evaluating non-marginal projects (i.e., those with large intervals) based on unit changes in a non-monetary metric.

A reasonable way to illustrate the social trade-off inherent in compensation is through a concave indifference curve like U_1 in Figure 10, indicating decreasing marginal rates of substitution. For example, at B_1 there is an abundance of Q_2 and we are *relatively* willing to tolerate environmental damage so long as we receive some amount of Q_1 (restoration) in return. At B_2 we are *relatively* unwilling to tolerate reductions in Q_2 (steep slope), which means we require relatively large amounts of Q_1 in return.[41] Welfare economics suggests that restoration projects be evaluated based on these types of social preferences (assuming they can theoretically be measured). In practice this usually requires a linear approximation of preferences (slope) around a small given marginal project. An example is the "damage-restoration" project from point A_1 to A_2 in Figure 10, where the line tangent at A_3 (thick dashed line) is an assumed linear approximation of preferences at A_1 and A_2, respectively (thin dashed lines). The key assumption underlying EA in general is that restoration projects cover a relatively small interval, such as from A_1 to A_2.

Figure 10 Linear approximation of social indifference curves vs. constant value across quantities



[41] This is intuitive. If contamination of a 10 acre wetland represents the last 10 acres of wetland available in a region, society may place a very high value on that loss and therefore demand high amounts of compensation.

If instead, a project is non-marginal (i.e., covering a significantly large interval[42]), then a linear approximation of preferences is no longer defensible: i.e., the thick dashed line tangent at A_3 is not a reasonable approximation of the preferences (slopes) at B_1 and B_2, respectively. Such projects can still be assessed based on social preferences, but generally require a more sophisticated model to determine how preferences change across the interval.[43] In the case of EA, this type of project can theoretically be evaluated by asking individuals in society how they trade-off the resources in question between, for example, points B_1 to B_2. A specific example of this is Breffle and Rowe (2002) who ask respondents in a choice experiment to value both the loss and gain as a *whole*, rather than relying on *constant unit changes in the non-monetary metric* (illustrated by U_2 in Figure 10) which is the conventional HEA/REA approach.[44] Thus, while it is possible to evaluate non-marginal restoration projects using HEA/REA (or even VEA), the EA framework analyzed in this report generally assumes a small marginal project (e.g., A_1 to A_2).

In summary, compensation should be informed by social preferences through an indifference curve, although a linear and constant[45] approximation of preferences across an interval -- which is inherent in the conventional HEA and REA approach where the ecological change is assumed to mirror the change in value that society attaches to the loss and gain of a resource -- may be reasonable for small intervals. However, it may not be reasonable for non-marginal restoration projects. Figure 10 underscores the fact that social preferences underlie the compensation scaling process and the constant trade-off across quantities that is inherent in the non-monetary metric framework of an HEA/REA may not be appropriate in all cases.

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[42] A non-marginal project is, of course, a relative term. As one reviewer pointed out, a small population of a rare species, say 50 individuals, could result in a non-marginal "damage-restoration" project if only 10 of those are affected (i.e., one-fifth).

[43] Non-marginal projects are generally evaluated in a CBA framework through a general equilibrium model.

[44] An alternative solution to this "constant value across quantities" inherent in the REA/HEA would be to value the damage and restoration in monetary terms, as in a Value Equivalency Analysis.

[45] Note that in some cases this constant linear value may not be a simple one-to-one ratio. The use of a habitat scalar explicitly values the linear trade-off. For example, a scalar may suggest that a damaged wetland acre be replaced by two acres of restored upland (see English et al 2009).

- **Compensation can only satisfy society in the aggregate**. While compensation may be measured (or scaled) in monetary or non-monetary units, its provision can only be in resource-based units. Thus, the EA approach to compensation is differentiated from the economic welfare approach by the legal requirement for a resource-based compensation mechanism, rather than private goods or money. The "time discrepancy" problem implies that a "pay-back" of what was lost is not sufficient compensation. Further, because resource compensation is a public good, compensation can only be provided on a societal (not individual) level. In a theoretical economic framework, compensation should be distributed across society such that differing amounts of the compensating mechanism is paid to individuals, depending on the size of their utility loss (Flores and Thacher, 2002).[46] However, because environmental resources are a non-divisible compensation mechanism (e.g., a public good), we cannot "cut up the pie" and distribute it according to welfare losses. This is in part due to the market failure inherent in public goods. Thus, compensation can only satisfy society in the aggregate; it is impossible to satisfy specific individuals with heterogeneous preferences when the compensation mechanism is a non-divisible resource (Jones and Peace 1997).[47]

  Even if the compensation mechanism was divisible, the EA approach does not account for heterogeneous preferences. Instead, EA assumes that a fisherman and a non-fisherman hold the same value for the loss of a fishing resource and are compensated accordingly. If instead, a fisherman is more greatly impacted by the loss of a popular sport fishing species, he/she will not obtain any more compensation than the non-user. This is equivalent to having a simple linear SWF, where the trade-offs in utility of different

[46] The use of money also ensures an efficient approach to compensation. In this sense, the legal requirement that environmental loss be compensated with resources (instead of money) leads to inefficiencies in the same way that a barter system (rather than using money as a medium of exchange) leads to economic inefficiencies. However, these requirements are motivated by social preferences for maintaining natural capital - see first bullet in Section 5.

[47] A reviewer noted that one could imagine a situation where local damage and restoration only benefits the group of individuals that were harmed (e.g., fishing loss and compensation at a remote lake where only a small community is affected). This may be true for use values for that community, but those who live far from the site cannot be excluded from benefitting from non-use values generated by the restoration project.

households is treated equally or, alternatively, that everybody has identical utility functions.

- **Constant values over time**. The EA framework holds the value of a resource constant over time (all else equal[48]) and assumes that a replaced resource has equal value to the lost resource. This approach was motivated by the presumed difficulty in estimating the economic value of damaged and restored resources (Unsworth and Bishop 1994). This inherent assumption may not hold if remediated acres provided in the future are more scarce than the acres lost today. Importantly, this constant value over time is not inconsistent with our use of a positive time preference, which (all else equal) assumes that we are impatient and place higher value on things that occur today and less value if we have to wait for them.
- **A dual purpose proxy**. The use of a non-monetary metric in an HEA/REA rests on one ecological and one economic assumption: (1) that the ecological metric is a good proxy for describing the ecological change that occurs and (2) that the quantifiable change in this ecological metric also mirrors the change in value the public holds for these resources. Under (1) we assume for example that by relying on changes in the population of an indicator species in a polluted river (e.g., number of salmon), we are jointly capturing all of the complex environmental changes occurring as a result of damage and restoration. Under (2) we assume that the decline in the salmon population is directly proportional to the assumed utility change.

  Assumption (1) is related to the challenge ecologists face when assessing the success of primary restoration, which can only be meaningfully judged in terms of an ecological metric. For example, determining whether a key resource has returned to its baseline is usually based on a quantification metric (e.g., species abundance). Whether or not the ecological metric captures the true environmental change Assumption (2) goes a step further by using that same metric to inform the adequacy of compensatory/ complementary restoration. The challenge with compensatory/ complementary restoration in an REA or HEA is to indentify a non-monetary metric that reflects the value society places on the damaged/restored resources because its selection reflects more

[48] In other words, ignore the effect of discounting for the moment.

than the tangible ecological parameter it measures (English et al 2009).

- **The challenge of ecological (i.e., non-monetary) metrics**. In some cases an ecological metric may not fully capture the environmental dynamics of an ecosystem[49], which may lead an HEA/REA to wrongly conclude that a resource is restored and society compensated.[50] Wakefield et al (undated) identify a hypothetical but plausible example involving a bird population affected by an oil spill. The authors suggest that a problem may arise due to conflicting foci of otherwise reasonable ecological metrics. A "Discounted Bird Year" (DBY) metric in an REA[51] tends to favor population size in the short-term, while conservation biology tends to favor metrics that focus on a minimum sustainable population over the long term (Figure 11). The result is

  > " ... that restoration [may be] judged to be sufficient using REA yet there is an increased risk of extinction. The converse also is true; one could restore the population as measured by extinction risk, while not achieving REA based restoration."

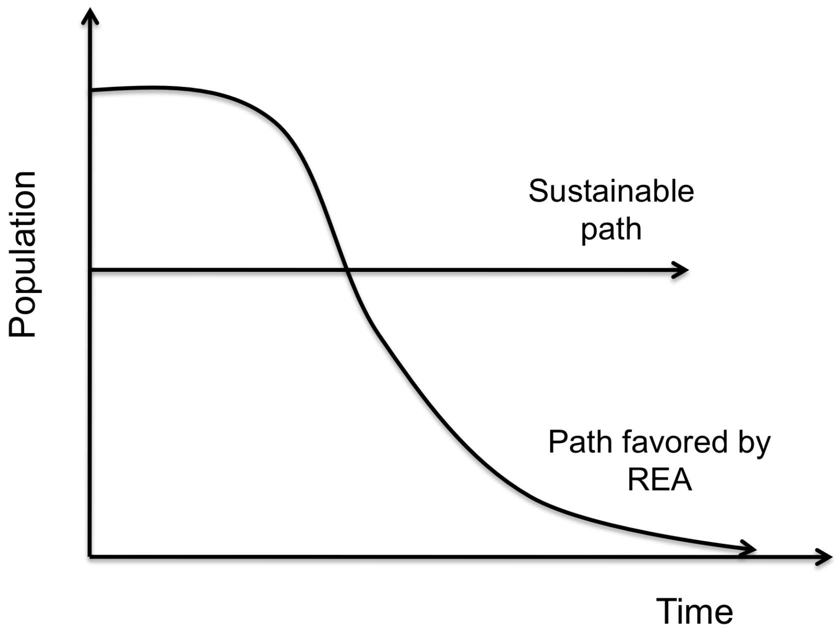
  Importantly, selecting an appropriate ecological metric is more than a conservation biologist's scientific challenge; in the case of HEA/REA such non-monetary metrics must also assume the role of proxy for welfare impacts.

[49] Peterson and Lipcius (2003) identify the progress required to improve the use of ecological metrics for scaling restoration.

[50] One reviewer noted that this problem may also arise with monetary metrics. Indeed, if an individual is not well-informed about the ecological implications of a hypothetical environmental damage scenario, than the indirect monetary measure of utility change derived from a stated preference survey may not necessarily ensure adequate compensation.

[51] See Paper II for an example using DBYs.

Figure 11 Comparison of ecological metrics (source: Wakefield et al, Undated)



- **Replacement cost approach**. By assuming that the ecological metric reflects changes in underlying utility, an HEA and REA also assume that the proxied utility change is proportional to the costs of restoring, re-placing, enhancing, or acquiring the equivalent level of resource (Unsworth and Bishop 1994). It is of course impossible a priori to know whether the cost of replacing the resource is greater than, equal to, or less than the money measure of the underlying utility change. It may actually be a reasonable assumption in the case of small marginal environmental changes to non endangered species, but this is uncertain.
- **Compensation for irreplaceable/unique resources**. Economics provides us with a framework for determining adequate compensation but it rests upon the assumption of substitutability. Without substitutability, the theoretical economic framework no longer applies. However the EA approach can address the loss of unique or irreplaceable resources by making a distinction between "irreplaceable" and "un-substitutable." In the un-substitutable case, nothing can be used as substitute (not even money). However, in the irreplaceable or unique case, a resource can still be substituted

by another sufficiently similar resource. Consider an oil spill that kills off a local population of an endangered bird species that has extraordinary significance or value to individuals living in that area. Under the traditional assumption of substitutability, a resource equivalency analysis may proceed by assuming that we can trade-off damage to that resource by providing either (1) more of that resource (e.g., a breeding program that re-introduces the species in the future) or (2) more of another type of resource that is traded for the damage resource (e.g., a habitat restoration program that encourages re-colonization by another type of similar bird species). In practical (legal) terms, the public must be compensated for environmental damage. EA makes the assumption that the public is willing to substitute resources that are "of a similar type or quality", if not identical.

- **Use of EA outside of the ELD is uncertain**. The requirements for *primary*, *complementary* and *compensatory* restoration (*remediation*) in assessing the *interim loss* of resources to the public is based on specific legal requirements of the Environmental Liability Directive, as well as under US OPA and CERCLA regulations. Whether or not these specific legal requirements -- defined in economic terms -- are relevant to environmental compensation under other EU Directives or other US statutes is not entirely clear. Although the concepts, which are founded on sound ecological and economic grounds, are readily transferrable to other environmental compensation cases, the specific legal requirements may affect the scaling methods used in different cases.
- **Environmental compensation is not "free" for society**. Environmental economics identifies externalities as a market failure that can be addressed by creating incentives for firms to internalize all the costs of production. This is the motivation behind the Polluter Pays Principle (PPP) and the key impetus behind the EU's ELD. While the PPP provides incentives for the actions of individual firms on a microeconomic level, the costs incurred by these firms are ultimately born by society which owns these firms. Kriström and Johansson (2010) revise the Roach and Wade (2006) equations described above (see Equations (1) and (2)) in order to reflect the fact that a restoration project affects not only the environmental quality of the damaged resource (E) and the restored resource (E°), but also affects national income (y) by the cost of restoration (c). V_i

is the indirect utility function of individual i; the equality assumes c>0 and ΔE>0 across a simple two-individual society:

$$V_i(y_i - c_i, E + \Delta E, E° - CV_i^{E°} = V_i (y_i, E, E_i°) \qquad (4)$$

Thus, the equality in (4) reflects an individual's opportunity cost of the restoration project. In summary, we can say that just as an EA assumes a trade-off between damaged and restored resources, on the margin society cannot escape the trade-off between ecological services and financial resources (i.e., the opportunity cost of restoration).

- **EA does not determine net social benefits**. EA does not address the question of which restoration project to undertake. Although it does give non-economic criteria for selecting among alternative restoration projects, the main purpose of EA is to calculate the amount of compensation to offset loses based on an ecological metric. It does not reach a conclusion about which project is most cost-effective (e.g., restoring or re-creating a wetland) nor does it assess the net social benefits of undertaking a specific project (or undertaking any project). Reira (2008) asserts that HEA/REA "... do not seem to systematically pass a social CBA" due to the replacement cost approach. Further, the author posits that the alternative -- a VEA approach using a monetary metric -- may actually lead to a decrease in social welfare because EA does not explicitly consider the net social benefits of a given restoration project; rather it focuses on equating the value of loss to the value of gain.
- **Use of a non-monetary metric for CBA**. Although REA/HEA methods cannot be used to identify which restoration alternative is best, it has been suggested that a non-monetary metric may be an alternative to monetary valuation in the context of a CBA. For example, Roach and Wade (2006) used the results of an HEA that evaluated ecological damages from oil releases as an ex ante tool to estimate the social losses associated with such spills. The results were used within a larger CBA to assess the net social benefits of leasing lands for offshore oil drilling in the US. To do so, the authors make the assumption that the cost of providing adequate environmental compensation for future oil spills represents the social costs of the resource injury. That is,

  > "... assuming that humans derive utility from natural resources in proportion to the ecological services they provide, then compensatory

> restoration projects should provide approximately the same level of utility as was lost from the natural resource injury. ... [thus] the monetary cost of restoration is a social cost-- funds a responsible party pays toward restoration projects represent a loss to society. Thus, assuming appropriately scaled compensatory restoration, the cost of compensatory projects ... equals the social costs of the injury." (p. 425-426)

With these strong assumptions, the authors relied on the non-monetary metrics in an HEA to estimate the restoration costs, which then became a measure of social costs for a CBA. Kriström and Johansson (2010) recently identified some of the assumptions required to justify the use of non-monetary metrics in a CBA. They found that while monetary metrics for small (marginal) projects are convenient -- thanks to the Kaldor-Hicks simplification of seeking projects with a positive sum of compensating variations -- non-monetary metrics require stronger underlying assumptions in order to act as a compensated measure of utility change: (1) individual utility functions must be identical (due to the non-divisible public good) (2) welfare distribution in society must be optimal and (3) the project must be marginal.

As the title suggests, this thesis attempts to answer the question: Is society better off as a result of requiring polluting firms to provide environmental compensation scaled using non-monetary metrics? The only way to really know is to compare the results suggested by an REA/HEA to the theoretically "true" compensation estimated by a value-to-value VEA approach (assuming that projected losses and projected gains are actually realized). Dunford et al (2004) attempted to do this and found that a number of very strict assumptions were required to ensure an REA/HEA would in fact adequately compensate for the public's welfare losses, as measured by utility changes. On a more basic level it is reasonable to assert that society benefits when legislation addresses a market failure, such as external effects, by giving financial incentives to firms to internalize all costs of production. This is the stated objective of the ELD in Europe and should, in practice, reduce incidents of environmental damage from occurring in the first place. When damage does occur, EA provides an interdisciplinary framework for scaling environmental compensation that is grounded in economic theory -- namely social preferences -- and aims to improve society's welfare.

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