Habitat Equivalency Analysis: An Overview

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1. Introduction

1.1 Goals of the paper

Natural resource trustees are authorized to act on behalf of the public to protect the resources of the nation's environment. Serving as a trustee for coastal and marine resources, NOAA determines the damage claims to be filed against parties responsible for injuries to natural resources resulting from discharges of oil, releases of hazardous substances, or physical injury such as vessel groundings.[1] Habitat equivalency analysis (HEA) is a methodology used to determine compensation for such resource injuries. The principal concept underlying the method is that the public can be compensated for past losses of habitat resources through habitat replacement projects providing additional resources of the same type. Natural resource trustees have employed HEA for groundings, spills and hazardous waste sites. Habitats involved in these analyses include seagrasses, coral reefs, tidal wetlands, salmon streams, and estuarine soft-bottom sediments.

The goals of this paper are to present an overview of HEA and illustrate the method with a simple, hypothetical example. In section 1.2 below, we outline briefly the natural resource damage context for HEA applications and the conditions for use of HEA. An example of how HEA is used to estimate the appropriate level of compensation for injuries to natural resources is presented in section 2. Appendices A through C present an algebraic representation of the HEA calculations and provide detailed tables from the example.

[1] The Under Secretary for Oceans and Atmosphere (NOAA Administrator) acts on behalf of the Secretary of Commerce as a Federal trustee for natural resources under the Comprehensive Environmental Response, Compensation, and Liability Act ("CERCLA"; 42 U.S.C. § 9601 *et seq.*), the Clean Water Act (33 U.S.C. § 1251 *et seq.*) , the National Marine Sanctuaries Act (16 U.S.C. § 1431 *et seq.*), and the 1990 Oil Pollution Act ("OPA"; 33 U.S.C. § 2701 *et seq.*).

1.2 Use of HEA in natural resource damage assessments

Natural resource damage claims have three basic components: (1) the cost of restoring [2] the injured resources to baseline, or "primary restoration," (2) compensation for the interim loss of resources from the time of injury until the resources recover to baseline *plus* (3) the reasonable costs of performing the damage assessment.[3] Following statutory requirements, all recovered damages are used to restore, replace, rehabilitate or acquire the equivalent of the injured resources (or to cover the costs of assessments). Consequently, recoveries for interim losses are spent on "compensatory restoration" actions providing resources and services equivalent to those lost. To ensure full compensation for interim losses, the trustees determine the scale of the proposed compensatory restoration actions for which the gains provided by the actions equal the losses due to the injury. The damage claim then is the cost of implementing the selected primary and compensatory restoration actions (plus the costs of the assessment) or alternatively, the responsible parties may be allowed to implement the projects themselves, subject to performance criteria established by the trustees. To develop the restoration plan, trustees must determine and quantify injury, develop restoration alternatives that consist of primary and compensatory actions, scale restoration alternatives, and select a preferred restoration alternative. This paper examines a method for scaling restoration alternatives, HEA.[4]

For compensatory restoration actions, the scaling question is: what scale of compensatory restoration action will compensate for the interim loss of natural resources and services from the time of the incident until full recovery of the resources? The scale of compensatory restoration actions is conditional upon the choice of primary restoration actions. Consequently, for each restoration

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[2] Restoration refers to human actions taken after the removal of the cause of injury (e.g., after remediation of a hazardous waste site, removal of the vessel in the event of a grounding), to return an injured resource to its pre-injury conditions. We use the term in its broad sense, to encompass the statutory concepts of "restoration, rehabilitation, replacement, and/or acquisition of the equivalent" of the injured resources.

[3] At any point in time, baseline refers to the condition of the natural resources and services that would have existed had the incident not occurred. If the resources are not expected to recover fully, interim losses will be calculated in perpetuity.

[4] This description characterizes the process outlined in the natural resource damage assessment (NRDA) regulations implementing OPA (15 CFR Part 990) and in the proposed statutory changes to the CERCLA NRDA provisions (43 CFR Part 11).

alternative under consideration, the type and scale of the primary restoration actions are to be identified first.[5] Then the compensatory components of restoration alternatives can be scaled.

The process of scaling a project involves adjusting the size of a restoration action to ensure that the present discounted value of project gains equals the present discounted value of interim losses. There are two major scaling approaches: the valuation approach and the simplified service-to-service approach, which applies under certain conditions.

HEA is an example of the service-to-service approach to scaling. The implicit assumption of HEA is that the public is willing to accept a one-to-one trade-off between a unit of lost habitat services and a unit of restoration project services (i.e. the public equally values a unit of services at the injury site and the restoration site).[6] HEA does not necessarily assume a one-to-one trade-off in resources, but instead in the services they provide. Consider a marsh as the resource and primary productivity a resource service. Suppose the replacement project provides only 50 percent of the productivity per acre of marsh as the injured site would have provided, but-for the injury. In order to restore the equivalent of lost productivity per year, then, the replacement project requires twice as many acres of marsh. Habitat equivalency analysis is applicable so long as the services provided are comparable.

The assumption of comparable services between the lost and restored habitats may be met when, in the judgment of the trustees, the proposed restoration action provides services of the same type and quality, and of comparable value as those lost due to injury. In this context, there is a one-to-one tradeoff between the resource services at the compensatory restoration site and the injury site. Therefore, the scaling analysis simplifies to determining the scale of a restoration action that provides a quantity of discounted replacement services equal to the quantity of discounted services lost due to the injury.

In cases where services at the compensatory restoration site are not of the same type and quality or of comparable value to those injured, then the assumption of a one-to-one trade-off

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[5] This includes identifying the recovery trajectory from primary restoration.

[6] The concept of services refers to functions a resource serves for other resources and for humans. For example, a wetland habitat may provide on-site ecological services such as faunal food and shelter, sediment stabilization, nutrient cycling, and primary production. Off-site services may include commercial and/or recreational fishing, bird watching along the flyway, water quality improvements due to on-site water filtration, and storm protection for on-shore properties due to the creation of wave breaks. Human services include both use and non-use services, so the HEA approach measures and accounts for non-use services in the damage claim.

between the resources at the injury site and the compensatory restoration site may be inappropriate. In these cases, NOAA recommends that trustees evaluate whether the conditions for HEA are met and consider using the valuation approach as an alternative to determining the trade-off between injuries and compensatory restoration actions.

Necessary conditions for the applicability of HEA include that (1) a common metric (or indicator) can be defined for natural resource services that captures the level of services provided by the habitats and captures any significant differences in the quantities and qualities of services provided by injury and replacement habitats, and (2) the changes in resources and services (due to the injury and the replacement project) are sufficiently small that the value per unit of service is independent of the changes in service levels. [7] When choosing a metric to evaluate the quantity and quality of services provided per unit of habitat, the trustees should examine the *capacity*, *opportunity* and the *payoff* (*i.e.* benefits) of the services being provided as well as *equity* issues involved with the potential compensation projects (*i.e.* who loses and who gains as a result of the injury and the potential compensation projects). *On-site biophysical* characteristics (e.g., soil, vegetative cover, and hydrology) affect the *capacity* of an ecosystem to provide ecological and human services. *Landscape context* affects whether the ecosystem will have the *opportunity* to supply many of the ecological and human services and strongly influences whether humans will value the opportunities for services.[8]

Consider, for example, the wetland function of sediment trapping. A wetland's capacity to provide this function depends on such factors as slope and vegetative cover. The opportunity for the wetland to trap sediments depends on the expected flow of sediments from adjacent land, which will depend upon types of upland land uses (i.e., landscape context). The total value generated from water quality improvements due to sediment trapping will depend upon the uses

[7] A counterexample shows when this condition is not satisfied. Consider the value of harvesting another salmon when salmon are in abundant supply versus the value of another salmon when the harvest has failed in Alaska. The value of providing another pound of salmon may be substantially greater when the salmon are in scarce supply, all else equal.

[8] For a further discussion of these issues, see, *Scaling Compensatory Restoration Actions, Guidance Document for Natural Resource Damage Assessment Under the Oil Pollution Act of 1990*, National Oceanic and Atmospheric Administration, Damage Assessment and Restoration Program, 1997 and King, Dennis M., *Comparing Ecosystem Services and Values*, Report prepared for the National Oceanic and Atmospheric Administration, Damage Assessment and Restoration Program, January 1997.

of the affected downstream water bodies: the value will be greater if there are nearby shellfish beds and finfish spawning areas than if the water flows into a fast-moving river.

The choice of a metric to characterize services is key to determining whether HEA is applicable in a given context. On-site ecological attributes, such as stem density, canopy structure (density times height), or fish density, are sometimes used as a proxy for services; however, they are primarily indicators of *capacity*. It is critical to evaluate the role of landscape context to evaluate the *opportunity* to provide off-site, as well as on-site, ecological and human services.

2. Habitat Equivalency Analysis: An Example

In this section we provide a simplified example to illustrate the method. To complement the example, we provide the algebraic formula for solving an HEA in Appendix A.

We construct the following hypothetical scenario. [9] A heavy fuel oil released from a grounded tanker covered 20 acres of marsh composed primarily of smooth cordgrass (*Spartina alterniflora*) in 2000. The oil smothered significant portions of the marsh, penetrating the sediments in many areas and killing much of the biota. This injury impairs the function of the marsh habitat; the marsh provides food and shelter for animals, water quality improvements for downstream resources, shoreline stabilization and other natural resource services. In addition, the loss of marsh affects human services. For example, marsh habitat supports off-site human services through the production of fish that provide recreational and commercial services and through nutrient filtration that provides water quality enhancement.

Trustees identified a feasible restoration action for compensation: transplanting *Spartina alterniflora* at the injury site for primary restoration and transplanting *Spartina alterniflora* along with some minor regrading at a nearby site. The projects are expected to restore the same type and quality of resources and services. Further, given the similar landscape context of the injury and restoration sites, the trustees judged the projects would restore resources and services of comparable value as those lost.

Under these conditions, HEA applies as a framework for scaling compensatory restoration. The basic steps for implementation include:

[9] The size and the description of the hypothetical injury are not based on actual events and have been chosen simply to demonstrate the HEA calculation.

1. Document and estimate the duration and extent of injury, from the time of injury until the resource recovers to baseline, or possibly to a maximum level below baseline;
2. Document and estimate the services provided by the compensatory project, over the full life of the habitat;
3. Calculate the size of the replacement project for which the total increase in services provided by the replacement project equals the total interim loss of services due to the injury; and
4. Calculate the costs of the replacement project, or specify the performance standards in cases where the responsible party will be implementing the compensatory habitat project.

In the first two steps, trustees must specify numerical values for ecological parameters for both the injured site and the compensatory project site. For each point in time at both sites, the level of services must be characterized as a percent of the baseline level of services at the injured site. As previously noted, the baseline of services is the level of services that would have been provided at the injured site *but-for* the injury. In our example, we assume that local experts consider grass shrimp (*Palaemonetes pugio*) to be a very important (or key) species in this habitat and they believe that the presence of grass shrimp is highly correlated with many services provided by the marsh. The presence and density of grass shrimp may indicate the general health of the marsh vegetation and the availability of food for higher trophic levels. Therefore, we assume that service levels for the injured site and for the compensatory project site are a function of the baseline mean density of grass shrimp in the marsh. Studies indicate that the spill reduced the mean density of grass shrimp by approximately 50%. Using the mean density of grass shrimp as a metric for marsh services, we assume that the service level of the injured marsh prior to any restoration actions is 50% of its baseline service level. [10]

[10] Depending on the exact nature and extent of an injury, the mean density of grass shrimp relative to the baseline density may or may not serve as a good metric for the services provided by the marsh. Additional potential indicators of marsh services might include macrofaunal abundance, fish utilization, vegetative density and percent vegetative cover.

In step three, we calculate the size of the compensatory project for which the total increase in services provided by the replacement project just equals the total interim loss of services due to the injury. Because losses and gains are occurring in different years, we discount the losses and gains so that units reflect what they are worth in the present year, 2000. This makes units from different time periods comparable. The discount rate incorporates the standard economic assumptions that people place a greater value on having resources available in the present than on having their availability delayed until the future. [This process is analogous to financial calculations where, if a dollar is put into the bank today at 3% interest, there will be $1.03 in one year. A person is willing to deposit money in such an interest bearing account only if having $1.03 is (at least) as good as having $1 today.]

The annual discount rate used in a HEA calculation represents the public's preference towards having a restoration project in the present year, rather than waiting until next year. The economics literature supports a discount rate of approximately 3%. [11]

We list below the parameters necessary to complete a simple HEA.

Injured Area Parameters:

- Baseline level of services at the injury site;
- Extent and nature of the injury: the spatial extent of injury (in acres for example) and the initial reduction in service level from baseline at the injured site (characterized as a percent of the baseline level of services). These parameters may be combined to measure the "effective-acres" of an injury; [12]
- Injury recovery function (with primary restoration or natural recovery): the rate of (incremental) service recovery and the maximum level of services to be achieved (characterized as a percent of the baseline level of services);

[11] For a further discussion of discounting see: National Oceanic and Atmospheric Administration (1999) *Discounting and the Treatment of Uncertainty in Natural Resource Damage Assessment*. Damage Assessment and Restoration Program, Damage Assessment Center, Resource Valuation Branch. Technical Paper 99-1. Silver Spring, MD, February.

[12] Effective-acres may be illustrated with an example. If 30% services remain on an injured 100 acre site, the injury totals 70 effective-acres (100 * (1-0.3) = 70). Note that the percent is represented by its decimal equivalent.

- Recovery period for injured resources: the dates when recovery starts and when maximum level of services will be achieved.

Replacement Area Parameters:

- Initial level of services at the replacement project site, as measured in effective-area (as a percent of baseline services at injury site);
- Replacement project maturity function: the rate of (incremental) service growth and the maximum level of services at the replacement project site (as a percent of the baseline level of services at injury site);
- Maturity period for replacement resources: the dates when services begin to increase and when the maximum level of services will be achieved;
- Replacement/creation project duration: lifetime of increased services.

Discount Rate

- Annual real discount rate

In the following section, we walk through the each of the steps and show how ecological parameters are developed from the injury and how the HEA equation is solved.

Step 1: Quantifying the losses from the injury. For our example, parameter values characterizing the injury are listed in the table below. As shown, we denote the injury to 20 acres of marsh function by specifying that, after injury, 20 acres provide 50% of the services relative to baseline at the time of the injury (2000). The site is projected to maintain a 50% service level until the primary restoration project (transplanting *Spartina alterniflora* at the injury site) is completed in 2001. The injured area is then projected to recover in eight years following a linear growth path to baseline.[13]

[13] The length and shape of the recovery function are chosen in order to simplify the presentation. An alternative recovery function, such as a constant growth rate or other non-linear growth path, and an alternative length of recovery, could be chosen if applicable to the injured resource.

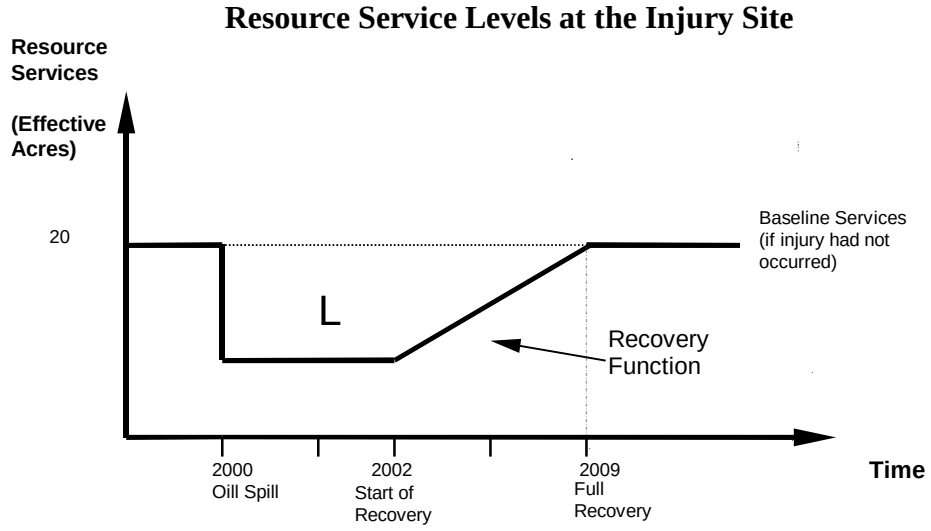
Table 1: Injury Parameter Values

Baseline Information of the Injured Resource:	
Habitat type injured:	Marsh
Year of injury	2000
# of injured acres:	20
Level of services in injury year (relative to baseline services):	50%
Recovery of Injured Habitat following Primary Restoration:	
Year restoration project ends and recovery starts:	2002
Years until full recovery:	8
Services at maximum recovery (relative to baseline):	100%
Shape of recovery function:	Linear
Discount Rate:	
Real annual discount rate	3.0%

The recovery of services provided by the injured habitat is illustrated Figure 1. On the vertical axis is the level of services provided by the injured resource, measured in "effective-acres". The effective-acres of services for a given year represents the product of the percent of baseline marsh services provided by an acre of the injured site times the number of acres injured.[14] When the injury occurs, in year 2000, the number of effective-acres of services drops from 20 to 10, because 50% services remain at the site. Services increase along a linear path beginning in 2002, until full recovery to the baseline at the end of 2009. Interim losses are represented in the diagram by the area labeled "L".

[14] In the multiplication, the percent is represented by the decimal equivalent, so the baseline level of acres is (1.00*20)=20. In 2005, the site is projected to operate at 75% of baseline, so the effective service level is ((1-.75) * 20) = 5.

Figure 1:



To calculate the measure of interim loss in present value terms, we must apply the yearly discount factor to the losses in each year. We calculate an interim loss of 50.84 discounted effective-acre-years by summing over all years of the injury. Appendix B presents the specific steps for calculating the discounted interim loss in services.

Step 2: Quantifying the gains from the habitat replacement project. The parameters characterizing the habitat creation project are listed in the table below. Prior to the compensation project, the nearby site offers 25% marsh services relative to the pre-injured marsh site. Service flows from compensation project commence when the project is completed in 2002. We project that marsh services increase during a 10-year growth period along a linear path and reach a maximum service level equal to 100% of the baseline service level of the injured site. We further project that the site will continue to function at the maximum service level in perpetuity.

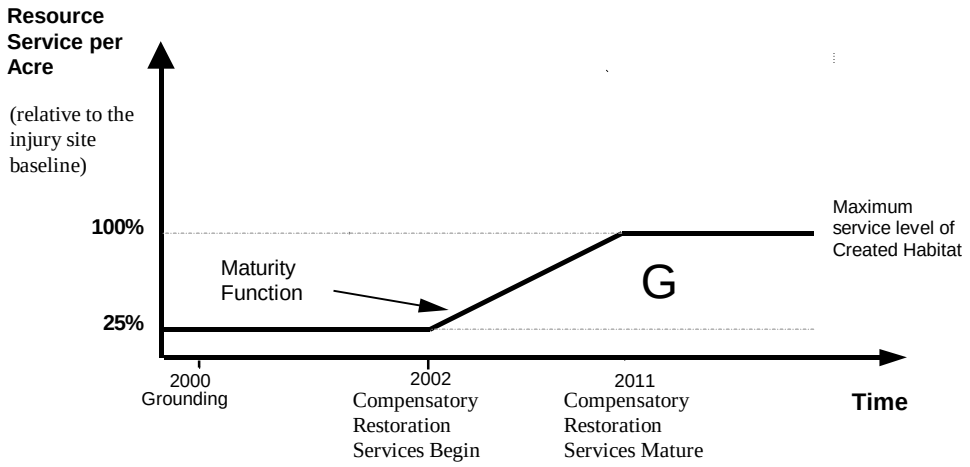
Table 2. Replacement Project Parameters

Replacement Project Characteristics:	
Replacement habitat type:	Marsh
Initial level of services	25%
Year creation/replacement project starts	2001
Year services start increasing	2002
Year in which maximum service level is reached (end of period)	2011
Maximum service level	100%
Shape of recovery function	Linear
Expected length of service increase	Infinity
Replacement Project Comparison Parameter:	
Ratio of maximum services per acre at the compensatory site and the baseline services per acre at injured habitat.	1:1

The increase of services at the habitat creation site is illustrated in Figure 2. The vertical axis measures the services per acre of a replacement project as a percent of the baseline services per acre at the *injured site*. As shown, services begin at 25% and start increasing in 2002, following a linear path until the services reach full maturity in 2011. The services continue to function at the maximum level in perpetuity. The total increase or gain in services per acre, is shown as area "G", which is the area between the maturity function and the 25% service level.

Figure 2:

Resource Service Levels at Replacement Project Site



To calculate service gains in the present value terms, we must apply the yearly discount factor to the gains in each year and sum over the lifetime of the replacement project. This calculation, presented in more detail in Appendix C, indicates that each acre of replacement project provides 21.32 discounted effective-acre-years of services.

Step 3: Determining the Size of the Replacement Project. To determine the size of the compensatory project needed to compensate for the losses, we divide the total loss in discounted effective-acre-years by the gain per acre of replacement and get 2.38 acres, as outlined in Table 3.

Table 3. **Determining the Size of a Project to Compensate for Interim Losses**

- Injured Area = **20** acres

Present discounted interim losses = **50.84** effective-acre-years (See Appendix B)

- Present discounted lifetime gains per acre of replacement project = **21.32** effective-acre-years per acre (See Appendix C)
- Let **R** = # replacement habitat acres required for compensation.
- Equating lost services and replacement project gains:

  50.84 lost effective-acre-years = **21.32** effective-acre-years/ acre * **R** acres
- *Solving for the size R of the replacement project yields:*

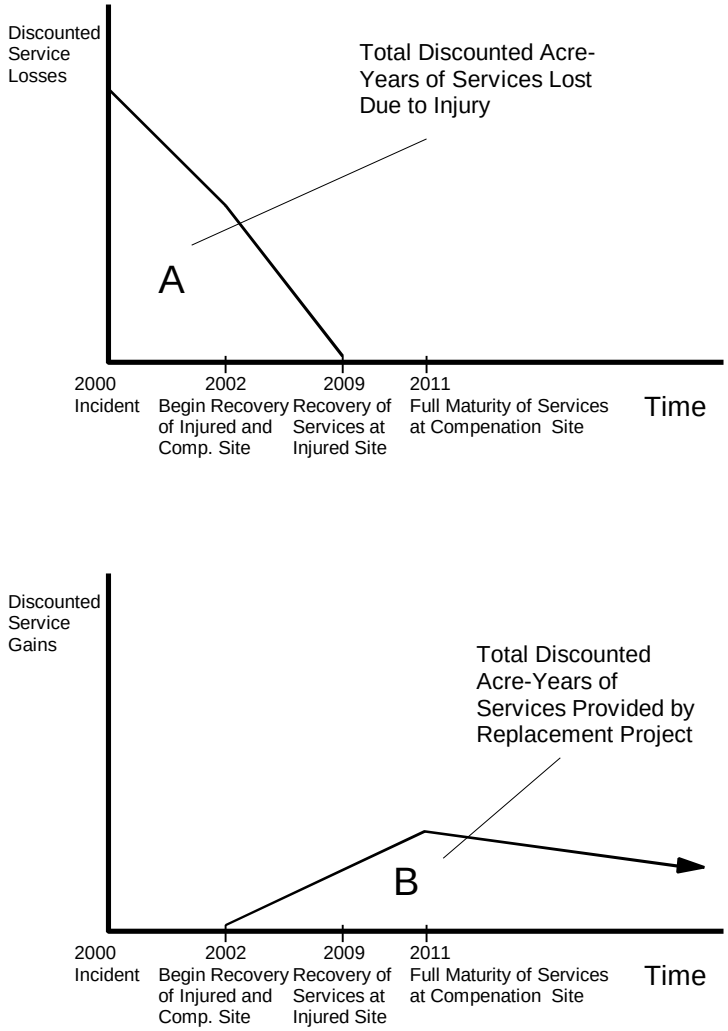
  R = 50.84/21.32

  = 2.38 acres of replacement habitat

The top graph in Figure 3 illustrates the discounted service losses resulting from the injury and the bottom graph illustrates the discounted service gains resulting from the replacement project. At the time of the incident, 2000, service losses occur and, although recovery doesn't start until the year restoration is completed in 2002, the value of future losses decreases in the year 2001 because the losses are discounted. The discounted losses reach zero in the year 2009, when the recovery of services at the injured site is complete. The total discounted service losses are equal to area "A" in the top graph.

The replacement project begins providing service gains in the year 2002, the year the compensation project is completed. In 2011, the compensation project reaches maturity and continues providing services at the same level in perpetuity. However, the value of these services declines over time, eventually approaching a value very close to zero (the value of the service gains approaches zero asymptotically) because the value of service gains is discounted. The total discounted service gains are equal to area "B" in the bottom graph. A replacement project of 2.38 acres will provide just enough service gains to equal the service losses resulting from the injury. That is, area "B" in the bottom graph of Figure 3 is made equivalent to area "A" in the top graph.

Figure 3:



Step 4: Calculating the Cost of the Replacement Project. Step four of HEA, which would be required for any damage assessment and restoration plan regardless of the methodology used in the assessment, occurs after the trustees have calculated the scale of the project. The damages claim is based on the costs of the replacement project.[15] Categories of project costs include the following:

[15] Again, it should be noted that the responsible parties may perform the replacement project, subject to performance criteria established by the trustees.

- planning and design
- environmental impact assessment
- permitting
- construction
- monitoring
- mid-course corrections

Some of the categories of cost can be characterized on a per-acre basis; others impose fixed costs (permitting). We do not calculate project costs in this example.

Appendix A: Algebra of HEA

Below, we outline the generic formula employed to calculate the appropriate scale of the compensation project. We first provide the notation for the HEA calculations.

Let *t* refer to time (in years), where the following events occur in the identified years:

t=0, the injury occurs

t=B, the injured habitat recovers to baseline

t=C, time the claim is presented (2000)

t=I, habitat replacement project begins to provide services

t=M, habitat replacement project reaches full maturity

t=L, habitat replacement project stops yielding services

Other variables in the analysis include:

V_j , the value per acre-year of the services provided by the injured habitat (without injury)

V_p , the value per acre-year of the services provided by the replacement habitat

x_t^j, the level of services per acre provided by the injured habitat at the end of year *t*

b^j , the baseline (without injury) level of services per acre of the injured habitat[16]

x_t^p, the level of services per acre provided by the replacement habitat at the end of year *t*

b^p, the initial level of services per acre of the replacement habitat

r_t , discount factor, where $r_t = 1/(1+r)^{t-C}$, and *r* is the discount rate for the time period

J, the number of injured acres

P, the size of the replacement project

We select a metric, *x*, for capturing overall level of habitat services, or habitat function, which could represent a single service flow from the resource or an index that represents a

[16] We simplify the representation of the baseline to be constant through time. Seasonal or inter-annual (or other) forms of variation could be incorporated, by adding time subscripts to the baseline variable *b*.

weighted average of multiple service flows. In the chosen metric, we define: x_t^j as the level of services per acre provided by the injured habitat at the end of year t, and b^j as the baseline level of services of the injured habitat; consequently, $(b^j - x_t^j)$ is the extent of injury in year t.[17] Analogously, we define x_t^p, as the level of services provided by the replacement habitat at the end of year t, and b^p as the initial level of services of the replacement habitat, prior to any enhancement activities; consequently, $(x_t^p - b^p)$ represents the *increment* in resource services provided by the replacement project - which is the relevant measure for our analysis. In our discussion in the text in the body of this paper, however, we referred to habitat services as a percent of the baseline level of services of the injured habitat, b^j ; in this format, $(b^j - x_t^j)/ b^j$ represents the percent reduction in services per acre at the injured site from the injured site baseline, and $(x_t^p - b^p)/b^j$ represents the percent increase in services per acre, relative to the injured site baseline, for the replacement site.

To translate the quantity in year t into an effective quantity in the year of the claim, C, we apply the discount factor $r_t = 1/(1+r)^{t-C}$, where r is the annual discount rate. Finally, the number of injured acres is J. The goal of the habitat equivalency analysis is to solve for the size of the replacement project, P.

[17] For ease of calculation all services flows are calculated from values at the end of each year. More precise estimates of the level of discounted service flows could be obtained by using smaller time periods (e.g. semi-annual or monthly). If smaller time periods are used the discount rate should be adjusted to keep the annual discount rate unchanged.

The equation equating the sum of the present discounted value of the services lost at the injured site with the sum of the present discounted value of the services provided at the replacement site becomes:

$$\left[\sum_{t=0}^{B} V_j * r_t * \left\{\left(b^j - x_t^j\right) / b^j\right\}\right] * J = \left[\sum_{t=I}^{L} V_p * r_t * \left\{\left(x_t^p - b^P\right) / b^j\right\}\right] * P$$

Under the assumption that the per unit value of replacement habitat services, V_p , is equal to the per unit value of injury habitat services, V_j , the calculation to solve for the size of the replacement project then becomes:

$$P = \frac{\left[\sum_{t=0}^{B} r_t * \left(b^j - x_t^j\right) / b^j\right] * J}{\left[\sum_{t=I}^{L} r_t * \left(x_t^p - b^p\right) / b^j\right]}$$

Note that the variables representing the per unit values of services drop out of the equation.

If the per unit values of lost and replacement services are not equal, then an alternative restoration scaling approach may be necessary. The HEA can still be applied if the value differences are known or can be estimated. In that case, the calculation to solve for the size of the replacement project is:

$$P = \frac{V_j}{V_p} * \frac{\left[\sum_{t=0}^{B} r_t * \left(b^j - x_t^j\right) / b^j\right] * J}{\left[\sum_{t=I}^{L} r_t * \left(x_t^p - b^p\right) / b^j\right]}$$

The ratio of $\frac{V_j}{V_p}$ is greater than one if the per unit value of the injured services is greater than the per unit value of the replacement services. Subsequently, more of the replacement project habitat would be needed than if the per unit values were equal. Less of the replacement project habitat would be needed if the per unit value of the injury habitat is less than the per unit value of the replacement habitat.

Appendix B: Interim Losses from a Marsh Oiling

The table below documents the injury and recovery of services on an annual basis and presents the sum of total discounted effective-acre-years lost. The first two columns identify the year and the corresponding status of the primary restoration project. The third column identifies service levels at the injured site as a percentage of the site baseline. Note habitat services grow for eight years following a linear recovery path, starting in 2002. Column four presents the percent service loss at the end of the year. In column five, effective-acres lost per acre are calculated by multiplying the service loss per year (in column 4) times 20, the number of acres injured. In column seven, the discounted effective acres lost are calculated by multiplying the effective acres lost (in column 5) times the discount factor (in column 6). For example, the service level of the injured site was 75% of baseline in 2005. In other words, the loss in services per acre was 25%. The undiscounted effective-acres lost is then 5 (20 acres * 0.25). The discounted effective-acres lost is equal to 4.31 (5 * 0.86).

Interim Losses due to Marsh Injury						
1	2	3	4	5	6	7
Year	Project Status	% Service Level (End of Year)	% Service Loss (End of Year)	Effective Acres Lost	Discount Factor	Discounted Effective Acres Lost
2000		50.00%	50.00%	10.00	1.00	10.00
2001	Primary Restoration	50.00%	50.00%	10.00	0.97	9.71
2002	Recovery Begins	56.25%	43.75%	8.75	0.94	8.25
2003		62.50%	37.50%	7.50	0.92	6.86
2004		68.75%	31.25%	6.25	0.89	5.55
2005		75.00%	25.00%	5.00	0.86	4.31
2006		81.25%	18.75%	3.75	0.84	3.14
2007		87.50%	12.50%	2.50	0.81	2.03
2008		93.75%	6.25%	1.25	0.79	0.99
2009	Recovery Complete	100.00%	0.00%	0.00	0.77	0.00
2010		100.00%	0.00%	0.00	0.74	0.00
2011		100.00%	0.00%	0.00	0.72	0.00
				Total Discounted Effective Acre-Years Lost =		**50.84**

Algebraic notation for table calculations (refer to Appendix A):

Column 3: $\frac{x_t^j}{b^j}$ at end of year

Column 4: $\frac{b^j - x_t^j}{b^j}$ at end of the year.

Column 5: *Column 4 * J*

Column 6: $r_t = \frac{1}{(1+r)^{t-2000}}$

Column 7: *Column 5 * Column 6*

Appendix C: Service Gains from Compensatory Restoration Project

In the table below, the increase in services of the compensatory habitat is calculated per acre of replacement project. The first two columns are the year the project starts, as in Appendix B. The third column identifies service levels at the compensation site as a percent of the baseline service level at the injury site. The forth column indicates the increase in the service level of the habitat for a given year as a percent of the baseline service level at the injury site. We multiply the increase in services per year (column four) times the discount factor (column five) to determine the total discounted effective-acres per acre per year. At the bottom of the table, the total discounted effective-acre-years per acre are summed.

Marsh Services Increase due to Replacement Project					
1	2	3	4	5	6
Year	Project Status	% Service Level (End of Year)	% Service Increase (End of Year)	Discount Factor	Discounted Effective Acres Gained per Acre
2000		25.0%	0.0%	1.00	0.00
2001	Replacement Project Begins	25.0%	0.0%	0.97	0.00
2002	Service Increase Begins	32.5%	7.5%	0.94	0.07
2003		40.0%	15.0%	0.92	0.14
2004		47.5%	22.5%	0.89	0.20
2005		55.0%	30.0%	0.86	0.26
2006		62.5%	37.5%	0.84	0.31
2007		70.0%	45.0%	0.81	0.37
2008		77.5%	52.5%	0.79	0.41
2009		85.0%	60.0%	0.77	0.46
2010		92.5%	67.5%	0.74	0.50
2011	Services Reach Maximum	100.0%	75.0%	0.72	0.54
2012 - "Infinity"	Services Continue in Perpetuity	100.0%	75.0%		18.06
Total Gain in Discounted Effective-Acre Years/Acre =					**21.32**

Algebraic notation for calculations (Refer to Appendix A):

Column 3: $\frac{x_t^p}{b^j}$ at end of year

Column 4: $\frac{x_t^p - b^p}{b^j}$, where $b^p = .25$

Column 5: $r_t = \frac{1}{(1+r)^{t-2000}}$

Column 6: *Column 4 * Column 5*