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Habitat Equivalency Analysis: A Potential Tool for Estimating Environmental Benefits

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PURPOSE: Estimates of the environmental benefits associated with U.S. Army Corps of Engineers (USACE) activities are increasingly becoming part of project requirements. This technical note describes Habitat Equivalency Analysis (HEA), a procedure that could potentially be applied to a wide variety of USACE projects to assist in calculating such benefits.

BACKGROUND: The focus of habitat restoration has evolved from simply replacing the physical area (i.e. acreage) of lost or damaged habitat to replacement of lost ecological services (e.g., functions and values). This change in perspective recognizes that not all parcels of habitat are of equal quality or yield the same quantity of services. A number of different techniques have been developed that can assist in estimating the appropriate amount of habitat to restore, including the Habitat Evaluation Procedure (HEP) (U.S. Fish and Wildlife Service (USFWS) 1980) and functional analysis based on hydrogeomorphic classification of wetlands, HGM (Smith et al. 1995). Unfortunately, these methods are specific to individual habitat types and may not be readily applicable to different spatial scales. Estimates of precisely how much habitat should be restored (the replacement or mitigation ratio) have often been based primarily on value judgments, and as a result have varied widely (Fonseca et al. 2000).

There may also be some uncertainty as to whether or not lost services have been completely replaced. Habitat Equivalency Analysis (HEA) is a method developed by the National Oceanographic and Atmospheric Administration (NOAA) to scale compensation for habitat damage resulting from oil spills and other contaminant-related impacts (NOAA 1997). The method focuses on complete, in-kind replacement of services lost between the time of impact and when the restored or created habitat becomes fully functional (Figure 1). HEA accomplishes this by incorporating the concept of discounting from economic theory. Discounting assumes that people place a greater value on services they can enjoy today than on those put off into the future. A standard discount rate of 3 percent is assumed; thus, for every year it takes to replace a specific amount of service, an amount of habitat capable of producing an additional 3 percent of the remaining lost service must also be constructed. For a more detailed account of discounting, see NOAA (1999).

HEA is already in use by both NOAA and the Minerals Management Service (e.g. Penn and Tomasi 2002, Roach and Wade 2006) and has been applied in situations as diverse as freshwater streams, seagrass beds, and coral reefs (Chapman et al. 1998, Fonseca et al. 2000, Milton and Dodge 2001). Because it is a generic method it can be adapted to a variety of situations, including evaluations of both habitats and individual species. Although HEA is a relatively new method, it has already been accepted as a basis for settlement in federal court (United States of America vs. Melvin A. Fisher et al. 1997); therefore, it should not require extensive proof-of-method prior to application.

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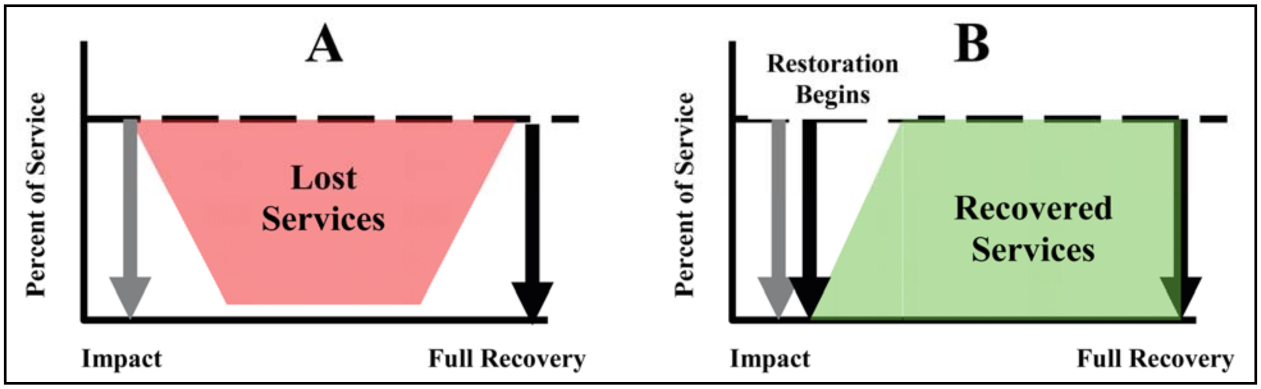

Figure 1. Estimation of (a) lost services, and (b) recovered services (after King (1997))

THE BASICS OF HEA: The structure of Habitat Equivalency Analysis is relatively simple. Calculations of how much habitat to restore or replace are based on estimates of the total loss in services supplied by the damaged or lost habitat. Total loss is estimated from the degree of initial damage to the resource and the loss in service that occurs during the time between the initial damage and when the restored or replaced habitat becomes fully functional. In a sense, it is analogous to paying off a bank debt. The borrower is required to pay back not just the principal (the amount of the debt) but also interest on any remaining debt incurred during the length of the payback. In this case the debt is the loss in ecological services and the payback is replacement of these services by restoration of the damaged site and/or by construction of new habitat.

Three critical pieces of information are necessary to make these calculations: 1) the nature of the service that has been damaged, 2) the extent of the initial damage, and 3) the rate at which recovery is likely to occur. Determining which service is most appropriate to replace and the degree to which the study area provided this service prior to impact are probably the most important and potentially the most controversial steps in the HEA process. Habitats provide multiple services and opinions may differ concerning which service should be the focus of restoration efforts. This is not an issue that HEA is capable of resolving but is one that must be negotiated by the interested parties. Likewise, estimating the degree of service supplied by a specific parcel of habitat prior to damage and the extent to which it has been damaged can be difficult, particularly when there is little supporting evidence or opinions differ regarding the original quality of the habitat. Again, this is an issue that must be negotiated between the interested parties and is not a function of HEA.

There must also be reliable information on the recovery rate of the service in order to accurately assess losses that occur while the restored habitat is developing to its maximum possible functionality. This type of information is generally available from the scientific literature, although in some cases it may require collection of field data or modeling efforts. Together with the estimated initial losses, this information yields the total amount of service lost over the period of the project and is used to scale the estimate of how much habitat must be constructed or restored.

It is also necessary to choose a metric or indicator of the service in order to monitor the degree to which the restoration efforts are meeting expectations. Fonseca et al. (2000) point out that the metric should represent the qualities and quantities of the service provided by both the impacted and restored habitats. It should also be easy to apply and relatively nondestructive. Metrics which represent more than one service have obvious advantages in that a more comprehensive assessment of losses and gains can be obtained. Finally, it is essential that the amount of service to be restored is small compared to the total available such that no change occurs in the underlying value per unit of service (NOAA 1997). NOAA (1997) uses the example of a fishery to illustrate this point. The value of a salmon fishery will vary as stocks become increasingly more abundant or scarce. In order to apply HEA, replacement of a portion of this stock should not be so large as to influence the overall value of the fishery, otherwise the appropriate amount of habitat to restore would change.

The structure of HEA and example calculations for analyses have been described by NOAA (1997), King (1997), Fonseca et al. (2000), and Allen et al. (2005a). An excellent overview is also provided by NOAA (online at *http://www.csc.noaa.gov/coastal/economics/habitatequ.htm*).

Conceptually, HEA proceeds in seven steps (Table 1). The area of the impacted site is estimated and a determination is made as to which service is to be the focus of restoration. It should be noted that while the basic calculations utilize a single service, careful selection of an appropriate metric to represent that service may result in multiple services being effectively covered. For instance, in a wetland, the shoot density of the dominant species may be used to represent primary production but would also reflect potential for sedimentation, utilization by resident fauna, and other ecological functions.

Table 1. Steps in an HEA Analysis
1) Determine the area of the impacted habitat
2) Select an appropriate service to replace and a metric to represent the service
3) Estimate the loss in service of the impacted habitat
4) Determine the shape of the recovery curve
5) Estimate losses occurring while recovery proceeds
6) Estimate total losses
7) Calculate the amount of restored habitat necessary to offset total losses

After selecting the service and metric, the extent of immediate loss in service to the impacted habitat is estimated. Next, the shape of the recovery curve (i.e. the recovery rate) is determined and losses incurred while the habitat recovers or develops are estimated. The immediate and during-recovery loss estimates are summed and the area of restored habitat necessary to offset all losses is calculated. In practice, the actual calculations are performed in a single operation using the following equations (Penn and Tomasi 2002).

$$\text{Total Losses}\,(L) = V_L * \sum_{t=i}^{B} A_L * (1+d)^{(T-i)} \tag{1}$$

where

V_L = value per unit area of injured habitat
A_L = area of injured habitat
B = year in which services are finally recouped
i = year of impact
t = number of years between impact and start of restoration
T = base year
d = discount rate (usually 3 percent)

Gains are calculated from a similar equation,

$$\text{Total Gains}\,(G) = V_G * \sum_{t=j}^{M} S_t * (1+d)^{(T-i)} \tag{2}$$

where

V_G = value per unit area of restored

S_t = additional area of restored habitat constructed in year t

j = year when gains begin

M = year in which services are finally recouped

T = base year

d = discount rate (usually 3 percent)

Estimates of how much habitat to restore (scaling) are made by making L (total losses) equal G (total gains). A free computer program for performing HEA is available online and can be accessed via the following URL: *http://www.nova.edu/ocean/visual_hea/index.html* (Kohler and Dodge 2006).

As an example of an HEA calculation, consider the following hypothetical project. A new work dredging project is going to remove 1 ha of unvegetated estuarine bottom habitat. As mitigation for the removal of the habitat, a beneficial use of the dredged material is proposed. The sediments will be deposited in nearby borrow sites subject to periodic anoxia (low oxygen conditions), which results in elimination of the benthic community. Raising the bottom will restore circulation, preventing oxygen depletion and restoring suboptimal habitat to a more natural state. The key question is how much habitat must be replaced. Following the seven steps listed in Table 1, the impacted area is determined to be 1 ha. In this case, a primary function (=service) of the habitat is to supply forage for estuarine fish, crab, and shrimp populations (Step 2). This service is best represented by secondary production or the total amount of animal tissue produced per year. It is assumed that the dredged areas will be permanently taken out of production and recovery time for the restored habitat will be two years (Steps 3 and 4). The results of steps 5-7 are presented in Table 2 using VISUAL HEA (Newell et al. 1998).

Table 2
HEA Results from VISUAL HEA

Year	% Service Level (end of year)	% Service Loss (end of year)	Effective Area Lost (hectare)	Discount Factor	Discounted Effective Area Lost (hectare)
2007.00	0.00	100.00	1.000	1.000	1.000
Beyond					33.333
Total discounted effective hectare-quarters lost:					34.333
Service Gain at the Compensatory Area					
Year	**% Service Level (end of year)**	**% Service Increase (end of year)**	**Discount Factor Gained**	**Discounted Effective Hectares**	
2007.00	0.00	0.00	1.000	0.000	
2007.25	62.50	62.50	0.971	0.607	
2007.50	75.00	75.00	0.943	0.707	
2007.75	87.50	87.50	0.915	0.801	
2008.00	100.00	100.00	0.888	0.888	
Beyond				29.616	
Total gain in discounted effective hectare-quarters/hectare:				32.62	
Replacement habitat size (hectare):				**1.053**	

In this case it will be necessary to fill a total of 1.053 ha of borrow site bottom to replace the lost natural bottom. The actual number of borrow sites to be filled and the depth to which they are filled will depend on the total volume of dredged material available and the volume of material necessary to adequately raise the bottom of the borrow sites.

CASE STUDIES OF HEA ANALYSES: The following section describes several examples of HEA applications to restoration projects. One of the earliest such applications was the Blackbird Mine Hazardous Waste Site in east-central Idaho (Chapman et al. 1998). The Blackbird site was mined for copper and cobalt for over 70 years and wastes from the mine seriously contaminated 40 km (25 miles) of nearby Panther Creek, a tributary of the Salmon River. Water quality, benthic fauna, and fish assemblages including Chinook salmon were negatively impacted by the wastes. The mine owners were required to perform cleanup operations and to restore the biological health of Panther Creek. Trustees responsible for monitoring the cleanup determined that the abundance of Chinook salmon was the best metric on which to base restoration since their abundance was considered a sensitive indicator of overall ecosystem health. HEA was employed to determine the level of effort necessary to ensure that there would be least 200 naturally spawning salmon present in the creek on an annual basis. This value was estimated from existing information from the Snake River. Based on a model of salmon life cycle, restoration was scaled to include a mix of efforts including establishing a salmon hatchery to restock the creek, creating new off-channel habitat, restoration of the natural meandering of the creek, and permanently fencing off several miles of land along the creek to keep livestock out of riparian habitat. Application of HEA to estimate efforts necessary to replace individual species is also known as Resource Equivalency Analysis (REA).

HEA has also been used to scale restoration of salt marsh habitat damaged by failure of an oil pipeline at Lake Barre in coastal Louisiana (Penn and Tomasi 2002). In this case, more than 6,500 barrels of crude oil were spilled damaging over 1,700 ha of marsh. Fortunately, 1,685 ha were only lightly oiled and were expected to rapidly recover. The remaining acres were heavily oiled and expected to recover far more slowly. Damage assessment determined that aquatic fauna including blue crabs, shrimp, and squid were impacted by hydrocarbons entering the water column, while birds such as egrets and ducks experienced either direct mortality or toxicity due to oiling. Using models from French et al. (1996), losses in aquatic and avian fauna were converted to biomass. The amount of salt marsh necessary to replace faunal losses was then estimated from known levels of salt marsh production and trophic level transfers. This information was then utilized in an HEA analysis to evaluate potential restoration scenarios including leaving gaps in marsh planting areas and the potential influence of erosion. Ultimately it was determined that a total of 1.5 ha of marsh was required to offset faunal losses and an additional 6 ha to replace the damaged marsh.

Fonseca et al. (2000) applied HEA to scaling of seagrass restoration to replace habitat damaged by treasure hunting activities in the Florida Keys. A total of 0.66 ha (1.63 acres) of turtlegrass (*Thalassia testudinum*) was destroyed by downward-directed prop wash, a common treasure-hunting technique to uncover buried items, near Grassy Key in the Florida Keys National Marine Sanctuary. Using seagrass shoot density as a metric and models of seagrass growth the authors estimated that the damaged habitat would require more than 17 years to recover naturally. Based on this recovery estimate, HEA calculations indicated that an additional 0.63 ha (1.55 acres) of seagrass would be required to recoup the lost services.

Figure 2. Craney Island Placement Site

In one of the few examples of HEA applied to a USACE project, Peterson and Associates (2003) estimated the area of habitat necessary to replace unvegetated, estuarine bay bottom and the associated water column sacrificed as part of an expansion of the Craney Island Dredged Material Placement Area on the Elizabeth River, Virginia (Figure 2). Peterson and Associates based their estimates on lost secondary production of herbivores (infauna and zooplankton) and made separate estimates for potential replacement of the bay bottom and water column habitat by either oyster reef or salt marsh habitat. In order to offset total losses for the 234-ha (580-acre) site, they estimated it would require between 2.0 and 7.4 ha (5.0 to 18.2 acres) of oyster reef habitat or 27.0 to 98.2 ha (66.9 to 243.2 acres) of salt marsh habitat. In this case, the authors recommended that a mix of oyster reef and salt marsh habitat be constructed, since the combination was likely to provide synergistic ecological benefits.

DISCUSSION: As with any method, HEA has both advantages and limitations. Among its advantages is that it is a general method, not inextricably linked to a specific habitat or a type of service, and therefore adaptable to a wide range of applications. It has already been successfully employed on the habitat scale to produce estimates for in-kind restoration of seagrass (Fonseca et al. 2000) and salt marsh (Penn and Tomasi 2002) habitats. HEA has also been employed in situations where only a single species rather than an entire habitat is of interest as in the case of the Blackbird Mine site where it was used to replace Chinook salmon (Chapman et al. 1998). Milton and Dodge (2001) have shown how HEA can be applied on both the landscape and population level for different components (stony corals, gorgonian corals, and algae) of Caribbean coral reefs and planning periods covering of different time scales. Strange et al. (2002) also discuss application of HEA to salt marsh restoration and provide a valuable summary of recovery rates for a suite of potential metrics. Bruggeman et al. (2005) have extended HEA to the landscape scale (describing it as Landscape Equivalency Analysis) to calculate conservation banking credits for restoring endangered species habitat. The authors used genetic variability of metapopulations as the metric for testing the ultimate effects and appropriate scales for restoration in fragmented habitats. Peterson and Associates (2003) have applied HEA to replacement of open bay bottom and water column habitats with salt marshes and oyster reefs.

Just as HEA has a number of advantages for calculating restoration ratios and therefore environmental benefits, it also has a number of limitations that need to be considered. Dunford et al. (2004) summarized these, pointing out that the underlying assumptions are frequently impossible to achieve, i.e. that damaged and restored habitats will eventually produce the same quantity and quality of services, the proportion of habitat services to habitat values is constant and that real value of services remains constant over time. The importance of the first assumption is supported by the fact that virtually every project incorporating HEA stresses the importance of understanding the landscape position of the injured and restored habitats and how this position contributes to the eventual capacity of the habitats to realize their potential contribution to providing services. Reliance on a single service and metric is another potential problem. While a powerful advantage in making the technique adaptable to a variety of applications, indiscriminate use potentially ignores the fact that habitats provide multiple services, many of which are important to assessing habitat quality. Most recent habitat assessment techniques such as HGM and Indices of Biotic Integrity (IBI) incorporate multiple metrics representing multiple habitat qualities or services. This limitation was recognized by the developers of HEA and, as previously mentioned, most applications attempt to utilize metrics that represent multiple services. Several authors suggest that application of multi-metric indices such as HGM or IBI's may represent an approach to dealing with this issue.

Another issue is the limitation to in-kind or service-for-service replacements. It is often either impractical to replace the lost service(s) or more desirable to create an out-of-kind restoration in order to address broader issues of ecosystem restoration. For example, when Peterson et al. (2003) proposed replacing open bay bottom and water column secondary production with that of oyster reefs or salt marshes, this could easily have been interpreted as out-of-kind replacement. While all four habitats produce this service, thus supporting higher trophic levels, they do so for slightly different faunal assemblages or different life history stages of the same species. This is not to imply that the recommendations were inappropriate since the ecosystem in question had already lost significant amounts of both reefs and marshes and their construction would provide much needed services. King (1997) indicates that a valuation approach is more appropriate for out-of-kind replacements, although these are too often focused on purely economic aspects of habitat services. Ludwig and Iannuzzi (2006) may provide a solution to this problem by combining the Analytical Hierarchical Process (AHP), a valuation method based on pairwise comparisons of ranked suites of alternatives, with HEA procedures. AHP is a mathematical technique that combines ranking of resources (e.g. support of wildlife, water quality), ranking of restoration alternatives based on their contribution to a resource, and a combination of the rankings to produce a weight for each alternative. By normalizing these weights, the authors create Habitat Equivalency Factors (HEF's), which can be incorporated into a HEA analysis. Ludwig and Iannuzzi (2006) provide an example application of this combined procedure to evaluation of restoration alternatives in impaired East Coast estuaries. They suggest that the combined HEA-AHP approach permits application to cases where the assumption of equivalent ecological services is not met, where there are multiple, not single, sources of stress (impact) to the ecosystem, and out-of-kind replacement is the most practical or appropriate restoration alternative. Allen et al. (2005b) combine HEA with REA and economic considerations to form the Habitat-Based Replacement Cost method (HRC). HRC estimates the economic costs necessary to generate the recouping of lost habitats and organisms.

In conclusion, HEA represents a powerful and adaptable technique that may prove to be of use in estimation of environmental benefits. It can be employed in a variety of habitats and spatial scales and applied to recovery either of habitats or individual species. HEA makes allowance for services lost during an injury and those incurred while restoration efforts are still reaching fruition. It also takes into account variable degrees of injury and those services recouped by natural recovery of the damaged habitat. Although there are certain restrictions to the use of HEA, careful consideration of its limitations and incorporation of appropriate safeguards make it a potentially valuable tool for resource managers.

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