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Application of Habitat Equivalency Analysis to USACE Projects

by Gary L. Ray

PURPOSE: Habitat Equivalency Analysis (HEA) is a procedure developed to scale compensation for habitat damage (National Oceanic and Atmospheric Administration (NOAA) 1997) with potential application to environmental benefits analysis. In a previous technical note the basic concepts underlying HEA, its strengths and weaknesses, and example calculations were described (Ray 2008). This technical note presents details of how HEA has been applied to a variety of U.S. Army Corps of Engineers (USACE) projects.

BACKGROUND: Over the last 40 years, the importance of habitat restoration to the mission of the USACE has increased to now be on par with flood control and navigation (Davis 1999). Based on legislative mandates resulting from the National Environmental Policy Act (NEPA) of 1969, the Federal Water Pollution Act (Clean Water Act) of 1972, and the Water Resources Development Act (WRDA) of 1986, as well as development of the USACE's Environmental Operating Principles (USACE 2004), the Corps has focused increasing effort on minimizing environmental impacts of USACE operations and restoring damaged habitats. To accomplish these efforts it has been necessary to develop new tools or modify existing ones to evaluate which restoration project or alternative plans within a project provide the most environmental benefit. Examples of such tools include habitat functional analyses such as the hydrogeomorphic method for wetlands (Smith et al. 1995), the Habitat Evaluation Procedure (U.S. Fish and Wildlife Service (USFWS) 1980) and Indices of Biotic Integrity (Karr 1981). Unfortunately, these methods are highly specific to individual habitats and require substantial investment in time and effort to modify them for new habitats.

HEA is an accounting technique for calculating complete, in-kind replacement of lost ecological services (ecological functions and values) resulting from an environmental impact (NOAA 1997). It is a generalized method and can be used in any type of habitat including freshwater streams (Chapman et al. 1998), salt marshes (Penn and Tomasi 2002), seagrass beds (Fonseca et al. 2000), and coral reefs (Milton and Dodge 2001). An estimate of how much habitat to create or restore is based on balancing the total amount of services lost with those supplied by restored or constructed habitat including services lost while the restored or constructed habitat is maturing or gained while the damaged habitat is recovering. HEA incorporates the concept of discounting from economic theory to ensure complete replacement of lost services by applying a standard discount rate of 3 percent to the total amount of services remaining to be restored. In this way, 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. The discount rate is based on the assumption that a greater value is placed on services available today

than on those put off into the future. A more detailed account of discounting and the HEA process is provided in NOAA (1997) and NOAA (1999). In the following sections examples of the application of HEA to USACE projects are provided in some detail. Further information for each of the projects can be obtained from the references therein or points of contact indicated for each case study.

CASE STUDIES:

Miami Harbor and General Reevaluation Report. Perhaps the earliest example of applying HEA to a USACE project is the Miami Harbor General Reevaluation Report and Final Environmental Impact Statement (U.S. Army Engineer District, Jacksonville 2002). The report describes plans to widen and deepen channels in Miami Harbor (Florida) which would result in impacts to hard-bottom reefs (Figure 1). The reefs are oriented parallel to the coast and directly intersect the entrance channel such that widening and deepening the channel will inevitably result in removal or damage to habitat. Four types of habitats will be impacted, two of which (rocky/rubble bottoms and unvegetated sand/silt/rubble bottoms) represent degraded habitats and will not require mitigation. The third, seagrass habitat, will require an almost three to one mitigation construction based on informal HEA calculations and consultation with resource agencies.[1] Formal HEA analysis was conducted on hard-bottom (limestone pavement) reef. Reef habitat was classified into two types: low-relief reefs, which are periodically buried by natural sand movement and high-relief reefs, which have a profile too high to be buried. Studies associated with the FEIS indicated that 0.6 acre of low-relief habitat and 2.7 acres of high-relief habitat will be impacted and require mitigation. These habitats support a diverse assemblage of sponges, algae, and soft and hard corals, provide habitat for larval fish, and are considered to be essential fish habitat. New reef habitats will be constructed by placing limestone blocks dredged from the entrance channel into approved artificial reef sites.

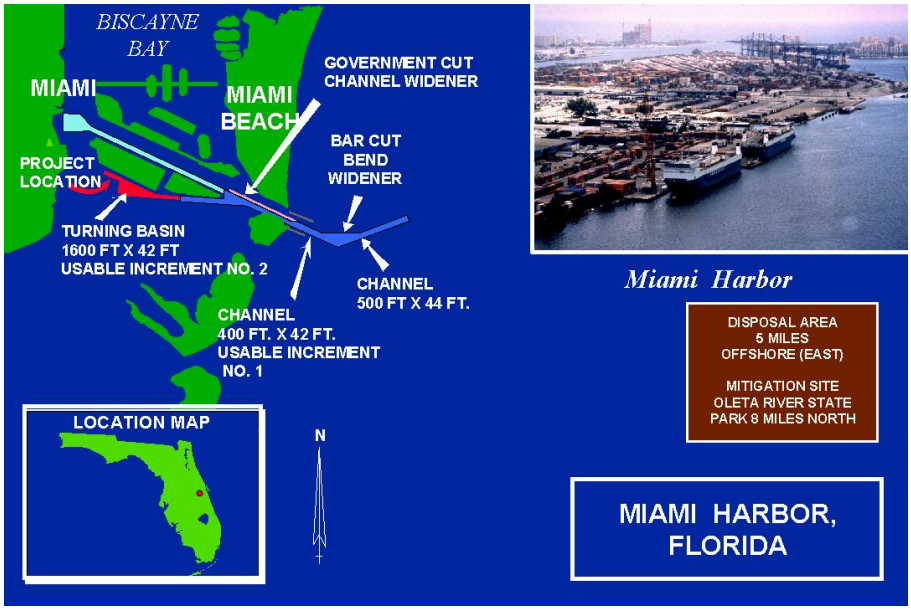

Figure 1. Miami Harbor (courtesy of U.S. Army Engineer District, Jacksonville)

[1] Personal Communication. 2008. Terri Jordan, Biologist, U.S. Army Engineer District, Jacksonville, FL.

As in any HEA analysis, several basic factors had to be determined or estimated beforehand. These include the appropriate metric to represent lost and replaced services, the total area of damaged habitat, the time interval between impact and mitigation, the relative loss of services, and the rate and form of the recovery curve. HEA for the Miami Harbor project was performed separately for each type of reef habitat. Assumptions common to both habitats included: 1) acreage-years of reef was the appropriate metric of function (total function produced by an acre of healthy reef per year), 2) there would be no time interval between impact and mitigation, 3) sufficient hard bottom would remain in the dredged areas to immediately provide at least 10 percent of habitat function, 4) placement of the limestone blocks dredged from the entrance channel in the artificial reef areas would immediately provide 20 percent of habitat function, and 5) recovery trajectories would be linear. Low-relief reefs were assumed to recover in approximately 12 years while high-relief reefs would require 30 years based on the rate of coral development and differences in the relative habitat complexity.[1]

HEA calculations for the Miami Harbor project were conducted using a spreadsheet approach in which cumulative losses and gains were produced for each habitat. Example calculations are presented in Table 1. The table lists effective acreage gain in low-relief reef habitat during the 12-year maturity period. For each year of this time period, the percent of service provided by the habitat is estimated, as well as the percent increase in service, the discount factor, and the discounted effective gain in acreage during that time period. The sum of the latter (discounted effective gain in acreage) represents the total gain per acre of replacement habitat, or 3.9 acres.

Table 1
Example HEA Calculations (Table A-2 from Miami Harbor GRR (U.S. Army Engineer District, Jacksonville 2002)

Year	% Service Level	% Service Gain	Discount Factor	Acreage Gained
0	20.00	0.00	1.00	0.00
1	26.67	6.67	0.97	0.06
2	33.33	13.33	0.94	0.13
3	40.00	20.00	0.91	0.18
4	46.67	26.67	0.88	0.23
5	53.33	33.33	0.85	0.28
6	60.00	40.00	0.82	0.33
7	66.67	46.67	0.79	0.37
8	73.33	53.33	0.76	0.41
9	80.00	60.00	0.73	0.44
10	89.67	66.67	0.70	0.47
11	93.33	73.33	0.67	0.49
12	100.00	80.00	0.64	0.51

To calculate the appropriate mitigation to compensation (m:c) ratio, the total effective loss was divided by the total effective gain (m:c = 3.07/3.90 = 1.3167). Since 0.6 acre was expected to be destroyed during dredging, a total of 0.8 acre (0.6 acre lost × 1.3167) will need to be created to replace the lost ecosystem services from low-relief, hard-bottom habitat. Similar calculations made for high-relief reefs resulted in a mitigation ratio of 2.0, thus requiring 5.4 acres of new reef to replace the 2.7 acres of high-relief reef predicted to be damaged. While later research suggests that some of the basic assumptions incorporated in these analyses could be revised, the basic approach remains valid. At the present time, this project has not received funds for construction.

The point of contact for more information on the Miami Harbor and General Reevaluation Report is Ms. Terri Jordan (Jacksonville District).

[1] Personal Communication. 2008. Jason Everett, Senior Ecologist, Dial Cordy and Associates, Inc., Jacksonville Beach, FL.

Broward County Shore Protection Project. The Final Environmental Impact Statement (FEIS) for the Broward County Shore Protection project describes plans to nourish nearly 12 miles of sandy beach along the southeastern coast of Florida (U.S. Army Engineer District, Jacksonville 2003). In reviewing the draft EIS, both state and federal resource agencies raised concerns that placement of the nourishment material would unavoidably impact nearshore hard-bottom (limestone pavement) habitats similar to those described in the Miami Harbor project. New reef habitat to mitigate for the lost ecological services was constructed by placing limestone boulders in nearshore reef sand pockets (Figure 2). Colonization of this new habitat was "jump-started" by transplanting corals from the sites to be impacted by the nourishment operations. HEA was employed to calculate the appropriate amount of new hard-bottom habitat needed to replace those services lost as a result of the nourishment operation.

In this example the metric used to reflect lost and replaced services was percent cover by corals. Corals dominate both the biological and physical structure of the hard-bottom habitat and are generally considered the most sensitive indicator of the health of the habitat. The total area of habitat impacted was estimated to be 13.5 acres of which 3.4 acres were sand, leaving a total area of 10.1 acres of hard-bottom habitat whose services would need to be replaced (U.S. Army Engineer District, Jacksonville 2002, Appendix F). Due to the nature of beach nourishment, not all impacts would be immediately felt so the time interval between impact and mitigation varied. For the HEA calculations it was estimated that only 20 percent of the total area would be immediately affected and the remainder would be impacted at a linear rate over the following three years. Once buried, it was assumed that all services from the impacted hard-bottom reefs would be lost forever. Services supplied by the constructed reefs were estimated to develop linearly to 100 percent in a period of 15 years assuming transplantation of 15-year-old corals harvested from reefs in the area to be impacted. Without transplantation it would take approximately 50 years for the new reefs to mature. Opinions concerning the degree to which services would be immediately supplied by the transplanted corals varied, ranging from 70 percent (based on the size and maturity of the corals) to virtually nil (based on the relatively sparse cover supplied by the transplants). A figure of 10 percent of total services to be immediately supplied by the transplants was negotiated among the various stakeholders. The actual

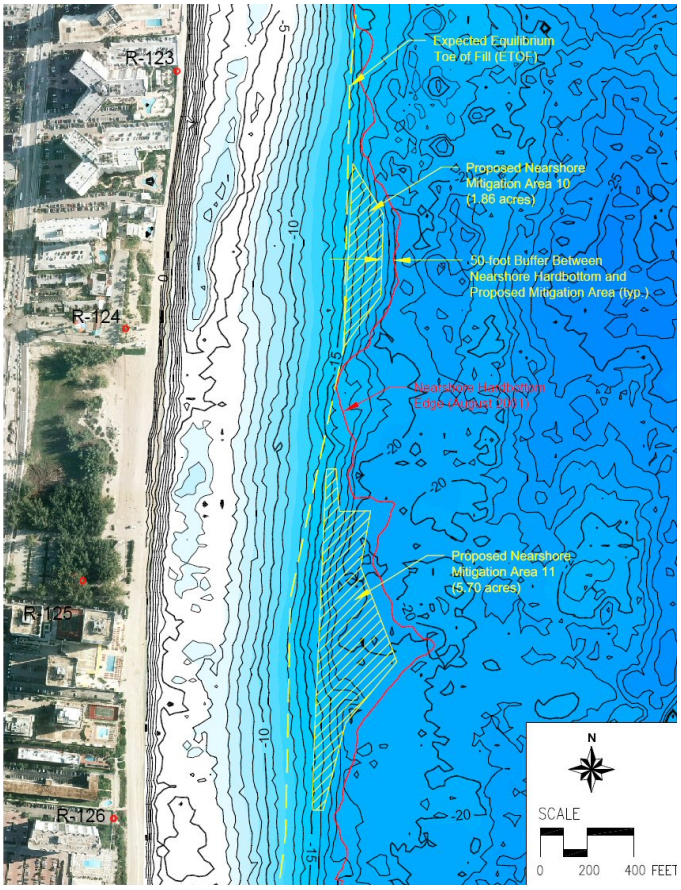

Figure 2. Location of hard-bottom reef mitigation sites (from Figure 6, U.S. Army Engineer District, Jacksonville 2003)

species, numbers of corals, and size of the coral heads to be transplanted were based on species and abundance estimates from habitats in the impact area and size frequency data from nearby monitoring stations. Using the standard discount rate of 3 percent and a recovery time of 15 years, HEA estimated that it would require 11.81 acres of new habitat to replace the 10.1 acres of reef impacted by the nourishment operation.

The project was initiated in 2003 and has been continuously monitored. Thus far, the created reefs appear to be developing as predicted with percent cover and diversity measures increasing over time (Carter and Prekel 2008; Hannes and Floyd 2008). Abundance, diversity, and size structure of both hard coral (Scleractinians) and soft corals (octocorals) are similar among created and natural habitats; however, the nature of their distribution varies. Hard corals are more evenly distributed on artificial than natural habitat while the opposite is true for soft corals.

The point of contact for more information on the Broward County Shore Protection Project is Ms. Terri Jordan (U.S. Army Engineer District, Jacksonville).

Craney Island. Craney Island is a 2,500-acre confined dredged material disposal facility located near Norfolk, VA (Figure 3). Constructed in the late 1950's to serve the greater Hampton Roads area, it receives material from a variety of maintenance, private, and permitted dredging projects and is approaching its capacity to receive new material. The Norfolk District has examined a number of disposal alternatives and is considering expansion of the site in an eastward direction (U.S. Army Engineer District, Norfolk 2008). The expansion would impact approximately 580 acres of unvegetated, estuarine bay bottom and the associated water column. These habitats are valued for their support of the estuarine food chain, supplying both primary and secondary production as forage for demersal and nektonic fishes and invertebrates. In order to compensate for the loss of these habitats, HEA was employed by Peterson and Associates (2003) to estimate the amount of either salt marsh or oyster bed habitat to create. This approach differs from previous examples in that the habitats being created are different than those being impacted (out-of-kind replacement). Oyster bed and salt marsh habitats were considered the most appropriate proxies to replace unvegetated bay bottom and water column habitats since neither of the impacted habitats can presently be recreated and oyster and salt marshes provide some of the same ecological services. Both oyster beds and salt marshes have suffered declines in the recent past in the estuary and are locally considered the preferred types of habitat to restore.

Figure 3. Craney Island Containment Facility (photo courtesy of U.S. Army Engineer District, Norfolk)

The HEA analysis was based on services common to all of the habitat types, secondary production of invertebrate herbivores (infauna and zooplankton). Separate estimates of loss were made for both bay bottom and water column habitat. It was assumed that the entire 580-acre area site would be impacted simultaneously and impact would completely remove all services from both habitats. It also was assumed that construction and maturation of the new habitats would occur prior to confinement area expansion. In this way it would be unnecessary to require application of the discount rate. However, the authors note that if this sequence is not followed it will be necessary to recalculate HEA using the 3-percent discount rate for the relevant time period. With the exception of salt marsh habitat, estimates of invertebrate herbivore secondary production lost and gained were calculated from estimates of standing crop biomass (converted to ash-free dry weight) multiplied by a production:biomass (P:B) ratio. The resulting value provides a uniform estimate of biomass produced during a year. The estimate for lost bay bottom services was made for both macrobenthos (species collected on 0.50-mm screen) and meio-benthos (species collected on 0.62-mm screen). Secondary production of macrobenthos was calculated from the average biomass values from samples collected at the proposed project site multiplied by both the high and low extreme production:biomass (P:B) ratios found in the scientific literature. Meiobenthos are far smaller than macrobenthos, however their production was assumed to be equal to macrobenthos due to their higher P:B ratios. Estimates of lost services for the water column were based on a similar technique employing macrozooplankton biomass values from nearby areas and multiplying the value by a range of P:B ratios. Secondary production of microzooplankton was estimated by multiplying the macrozooplankton values by a literature-based production ratio of macro- to microzooplankton of 5.75.

Estimates of services gained from the oyster habitat were based on biomass values from oyster restoration projects, P:B ratios for oysters from the scientific literature, and production values for macro- and meiofaunal invertebrates associated with oyster reefs. The total of these estimates was then halved to account for uncertainty about the relative success of local oyster restoration projects.

Services gained from the salt marsh habitat were estimated by a trophic efficiency method. In this procedure, literature values for vascular plant and microalgal primary production were converted to the proportion available to marine invertebrates, then adjusted assuming a trophic efficiency value of 10 percent. This value was subsequently doubled based on the observation that significant amounts of the available primary production are exported as evidenced by higher macroinvertebrate densities in subtidal areas near marshes.

In order to offset total losses for the 580-acre site, Peterson et al. (2003) 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. 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.

The point of contact for more information on the Craney Island Project is Craig Seltzer (U.S. Army Engineer District, Norfolk).

Barber's Point (Kalaeloa) Harbor Modification. The Honolulu District is presently in the feasibility stage of plans to modify the harbor at (Kalaeloa) Barbers Point on the island of Oahu (Hawai'i). Plans include widening and deepening the harbor and construction of a new jetty near the entrance channel. All of the alternative plans for the project will require dredging and construction activities that will affect coral reef habitats including nearshore reef flats, *Pocillopora* sp. dominated reef, *Porites* sp. dominated reef, and reef crest habitat. Potential mitigation for project impacts is a combination of relocating coral from the impacted area and removal of invasive algal cover from nearby reefs.

Figure 4. Barbers Point, Hawai'i (photo courtesy of USACE)

Under a contract to the U.S. Fish and Wildlife Service, the National Park Service has conducted HEA of the project alternatives. This analysis is still in the process of review; however, the most salient points of the analysis can be discussed. The metric to represent lost and replaced services was acreage-years of different coral reef habitats (nearshore reef flats, *Pocillopora* sp., *Porites* sp. and reef crest) and the total area of damaged habitat of each type was predicted from the footprint of each project alternative. Separate estimates were developed for damage resulting from anchoring, reef wall impacts, jetties, and pilings. Estimated initial loss of service was assumed to be 100 percent in all cases and while many impacts were temporary, a small area of habitat was predicted to be permanently lost under most alternatives. The shape of the recovery curve for temporary impacts was assumed to be linear and required a time period of 75 years. Estimates were made for potential mitigation efforts separately and in combination, providing a number of different options. Since the success of mitigation efforts and the supply of coral heads can be variable, estimates of the total area of coral to be transplanted and the area of invasive algae to remove from nearby reefs to compensate for lost habitat services was calculated for a range of values (50-100 percent).

The point of contact for more information on the Barbers Point Harbor Modification Project is Ms. Cindy Barger (U.S. Army Engineer District, Honolulu).

DISCUSSION: The case studies reported here describe application of HEA to a variety of habitats including hard bottoms dominated by coral, coral reefs, salt marshes, oyster beds, estuarine water column, and unvegetated muddy bay sediments. While all of these examples come from coastal habitats HEA was, in fact, developed not to be habitat specific. The preponderance of coastal examples is most likely due to the close interactions between USACE and NOAA. The approaches to HEA employed in the case studies differ in part due to the amount of information available concerning the structure, function, and recovery rates of the habitats, to the ability or lack thereof to recreate some habitat types, and also to the degree of experience with the method. HEA is still a relatively new technique and both the science behind the analysis and experience

with the method are still maturing. In many cases the information necessary for HEA may be lacking and values have to be based on best professional judgment. For instance, as an early application of HEA, many of the assumptions in the Miami Harbor project were based on limited information and many values had to be estimated.[1]

Different measures of habitat service were employed in most of the case studies even where the same habitat was involved. The Miami Harbor and Broward County analyses both examined hard bottoms dominated by corals but the first used total annual habitat function per acre (acreage-years) and the second, percent coral cover. The Barbers Point project also used acreage-years in its examination of impacts to Hawaiian coral reefs while the Craney Island project employed secondary production by herbivores in salt marsh, oyster reef, open-water bay bottoms, and water column habitats. Of the four case studies, Craney Island is the only one where the logic behind the choice of the measure was thoroughly described. This statement should not be construed as a criticism of the choices of the other case studies but rather as an observation that fuller documentation of this step would have benefited the analyses. For instance, both acreage-years and percent coral cover are commonly used proxies for habitat function, but this fact might not be obvious to a manager or decision maker unfamiliar with coral reef monitoring programs. The more documentation that can be provided to explain and support assumptions made during the analysis, the more likely it will be understood and accepted by those ultimately determining if the project will be funded.

One point of commonality among the case studies was that all based their estimates of the total area of damaged habitat on either pre-existing habitat maps or on project-specific mapping efforts. The availability of habitat maps is an important prerequisite to HEA that is sometimes not sufficiently emphasized in overviews of the procedure. Without accurate maps of what habitats are present, calculations of lost services could be severely under- or overestimated. Fortunately habitat maps for most terrestrial and wetland habitats are readily available and many state and federal agencies have ongoing efforts to map aquatic and marine habitats.

Not surprisingly, estimates of the relative loss of services varied among the case studies. This was because projects differed in the nature of the impact, their size and scope, and the degree to which individual habitats would be impacted. The Miami Harbor and Barbers Point projects both involved direct impacts from dredging, Broward County dealt with impacts associated with placement of beach nourishment material, and Craney Island was a dredge and fill project. The area of damaged habitat was obviously project-specific and ranged from a few acres to 580 acres.

The proportion of the project area experiencing loss in services also varied among projects. At Craney Island and Barbers Point, it was assumed that 100 percent of all services would be immediately lost in the project area with no possibility of recovery. At Craney Island the site was to be completely filled while at Barbers Point the entire area would be dredged. The Broward County beach nourishment project differed in the sense that while there would be 100-percent loss of services due to burial, the rate at which habitat would be impacted varied according to the expected progress of the nourishment operation. This difference in the temporal sequence of impacts could be easily incorporated into the HEA calculations, thus providing a more accurate

[1] Personal Communication. 2008. Jason Everett, Senior Ecologist, Dial Cordy and Associates, Inc., Jacksonville Beach, FL.

assessment of actual damage incurred. Likewise, it was possible to incorporate the fact that dredging associated with the Miami Harbor project would not equally impact the entire site but leave at least 10 percent of the ecological services intact into the HEA.

Estimates of the recovery time (or recovery trajectory) differed among projects, arising principally from the nature of the habitats involved. For instance, hard-bottom reefs encountered in the Miami Harbor project are areas of high physical disturbance (e.g., wave action, sand movement) and while dominated by corals are less diverse than coral reefs associated with the Barbers Point project. The low-relief hard bottoms were expected to develop to maturity within 12 years whereas the high-relief hard bottoms would require 30 years. This time differential between low- and high-relief hard bottoms was based on the observation that high-relief bottoms are more diverse and physically complex. Estimates of the recovery time were based on literature values and best professional judgment. The same habitats were involved in the Broward County project but the recovery time was increased to 50 years based on age estimates of corals in the project area. The 75-year recovery period used in the Barbers Point project was based on literature values and as previously mentioned reflects the greater diversity and complexity of Pacific coral reefs. The recovery estimate for oyster habitat in the Craney Island project, a year or less, was also derived from literature values. The prediction of a relatively short recovery period was based on the rapid developmental rate of oysters as well as the assumption that the site would be seeded with adult oysters immediately after habitat construction. The recovery rate for the salt marsh habitat was also estimated to be a year or less based on literature values.

These studies reflect many of the strengths of the HEA process but also illustrate some of the potential areas of difficulty. Perhaps the chief area of difficulty is when differences of opinion arise concerning either the choice of proxies for services or actual values for individual variables. For instance, in the Broward County project, estimates for the degree of service supplied by the transplanted corals varied from 0 to 70 percent depending on the opinion of the stakeholders and a value had to be negotiated (U.S. Army Engineer District, Jacksonville 2002). This is a common phenomenon and emphasizes the importance of having a “hands on” approach to the analysis. Representatives from many resource agencies may not have the same degree of experience with impacts from typical USACE operations such as dredging and can bring poorly informed views to the HEA development process. It is essential that experienced USACE representatives take an active part in the analysis, providing relevant information whenever necessary and ensuring that the best available science is incorporated at every step.[1] Another caveat is the importance of carefully documenting each step in the HEA process, particularly in presentation of both the logic and supporting documentation to support choice of proxies and values for individual variables. While the choices may seem obvious to the HEA team producing the analysis, it may not be so for those not directly involved in the process.

Among the strengths of the HEA process illustrated by these studies is its flexibility in application to different habitat types. In these cases, it was successfully applied to coral reefs, hard-bottom reefs, oyster beds, salt marshes, bay bottoms, and the estuarine water column. Likewise, it was possible to include differences in impact scenarios such as the physical extent (Miami Harbor) or temporal sequence (Broward County) of impacts into the HEA. It was also possible to evaluate multiple restoration alternatives (Craney Island and Barbers Point) and to

[1] Personal Communication. 2008. Terri Jordan, Biologist, U.S. Army Engineer District, Jacksonville, FL.

incorporate different levels of uncertainty in mitigation success (Barbers Point and Craney Island).

While HEA is presently still in its infancy with regard to USACE projects, its flexible nature and generality show great promise for application to calculation of environmental benefits. Future improvements in HEA such as use of multimetric indices (e.g., HGM or IBI's), standardization of potential input variables (e.g., choice of service metrics), improved sources of information on variable values (e.g., rates of recovery), and increased familiarity with the HEA process will undoubtedly increase both its use and utility in USACE projects.

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> Ray, G. L. 2009. *Application of habitat equivalency analysis to USACE Projects*. EMRRP Technical Notes Collection. ERDC TN-EMRRP-EI-04. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

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