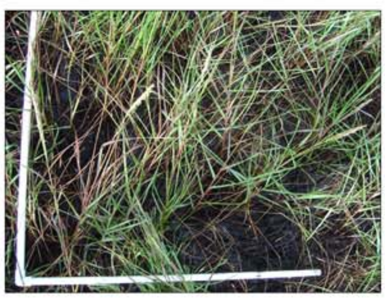
Measures of Ecosystem Function for Habitat Equivalency Analysis

Workshop Summary



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UNH-NOAA Coastal Response Research Center

Durham, New Hampshire

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The Coastal Response Research Center, a partnership between the National Oceanic and Atmospheric Administration (NOAA) Office of Response and Restoration (ORR) and the University of New Hampshire (UNH), develops new approaches to spill response and restoration through research and synthesis of information. The Center's mission requires it to serve as a hub for research, development, and technology transfer to the oil spill community. To better guide future restoration efforts, the Center and ORR's Assessment and Restoration Division (ARD) co-hosted a workshop to develop metrics to be used in Habitat Equivalency Analysis (HEA). HEA is used after injuries to natural resources resulting from discharges of oil, releases of hazardous substances, or physical injury into the environment has occurred. It is a method that helps determine the scale of compensation, in the form of habitat replacement projects, for such natural resource injuries. The workshop, entitled "The Habitat Equivalency Analysis Metrics Workshop", was held in December 2007 at UNH (Durham, NH). This report provides a summary of discussions that occurred at the workshop, and the matrix of metrics developed. Participants represented a broad spectrum of constituencies and expertise including governmental agencies, industry, and non-governmental organizations. This report is designed to serve as a resource for responders and government entities, to aid them in selecting the most appropriate metrics for use in HEA, with the goal of accurately depicting damage to coastal environments.

We hope you learn from reading the report and exploring the topics. If you have any comments about it, please contact the Center. We look forward to many more similar endeavors during the coming years where the Center can be of service to the response and restoration communities, helping to protect coastal ecosystems.

Sincerely,

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ACKNOWLEDGMENTS

The Coastal Response Research Center (CRRC) gratefully acknowledges the effort put forth by the workshop organizing committee. This workshop was successful in large measure because of the strong leadership and insights from NOAA's Office of Response and Restoration staff: Troy Baker, Kate Clark, Tom Dillon, Lisa DiPinto, Gary Shigenaka, and Ben Shorr and CRRC's Joe Cunningham. This oversight committee was tireless in the workshop planning, facilitation, oversight, report writing, and editing. The thoughtful discussions from the workshop participants - resource managers, academics and industry representatives - who are HEA practitioners, about the state of the science, evaluations and assessments of the current suite of commonly applied metrics, and ideas for future research and areas for HEA growth and development ranged across a wide array of viewpoints. Thanks to their contributions, we have advanced the state of understanding of HEA and captured it in this workshop report.

The Coastal Response Research Center is funded by NOAA's Office of Response and Restoration.

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I. Introduction

Coastal habitats are at particular risk of injury due to oil spills, hazardous substance releases, vessel groundings, and other damaging actions because of their proximity to population centers, shipping channels, and oil transportation, storage and transfer activities. Through the formal process of Natural Resource Damage Assessment (NRDA), the public can be compensated for losses of natural resources through habitat restoration projects that provide services of the same type and quality, and of comparable value as those lost (NOAA 1996). Damages claims for natural resource losses consist of three components: (1) the cost of restoring the injured resource to baseline (primary restoration), (2) compensation for the interim loss of resources from the time of injury until the resource has been restored to baseline (compensatory restoration), and (3) the cost of performing the damage assessment.[1] The goal of compensatory restoration is to compensate the public for the loss of habitat resources and resource services that were lost as a result of the incident.

Habitat Equivalency Analysis (HEA) is a methodology commonly used to determine compensation for such resource injuries. The services lost in the event must be quantified in order to determine the type and scale of the restoration actions for which the gains provided by the restoration actions equal the losses due to the injury (NOAA 2006). HEA is a tool that was developed to speed determination of compensation to reconcile injuries to the ecosystem. HEA is not typically applied to determine restoration requirements for human use losses, but is often used in conjunction with more appropriate methods more tailored to human use evaluations (e.g., contingent valuation, travel cost method).

There are four basic requirements for HEA to be considered: (1) an ecosystem service has been adversely affected, (2) the change in ecosystem services due to the injury and the compensatory restoration can be estimated, (3) recovery rates can be estimated, and (4) feasible restoration projects exist.

In order for HEA to be accurate and effective, the ecological services lost must be appropriately quantified. This is accomplished through the use of specific metrics, which will capture significant differences in the quantities and qualities of services provided by injured and replacement habitats (NOAA 2006). Oftentimes, habitat attributes such as stem density, biomass, and abundance are applied as service proxies. Habitat functions are often complex and provide numerous services, therefore, a metric that best captures the relative differences in the quality and quantity of those multiple services is required. The same metrics used in HEA may be used outside of NRDA claims process and can help guide restoration planning of habitat projects.

Salt marshes are among the most important ecologically important systems in the world. As an interface between the terrestrial, estuarine, and marine environments, they are among the most biologically productive systems and provide numerous benefits, including buffers during storm events, retention of nutrients and sediments, natural water quality treatment systems, and biodiversity preservation. Salt marshes are also highly susceptible to injury from oil spills

[1] Environmental laws addressing injury to natural resources include Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA/Superfund codified at 15 CFR 990) and the Oil Pollution Act of 1990 (OPA codified at 15 CFR 990).

(including cleanup actions), hazardous substance releases and vessel groundings (through scouring), and recovery may take years to decades.

When an injury occurs to a salt marsh, a HEA can be performed to quantify the degree of compensation required. However, in order to correctly determine the scale of the compensatory restoration, the ecological services lost in the marsh must be estimated using metrics specifically tailored to this complex ecosystem. If inappropriate metrics are used, there is a risk of over-compensation by the responsible party (RP), or under-compensation to the resources and the public.

Because of time and costs associated with developing and measuring metrics, HEAs often capture less than three metrics. Therefore, it is important that the metrics chosen not only accurately reflect the injury, but also include as many biological, chemical, and physical processes as possible. Choosing which metric(s) to use can often be one of the most difficult parts of HEA, especially in a diverse and dynamic system such as a salt marsh. Defining an "ideal" metric is challenging and a subject of continued debate. A workshop, hosted by the Coastal Response Research Center (CRRC) and the National Oceanic and Atmospheric Administration's (NOAA) Office of Response and Restoration (ORR) Assessment and Restoration Division (ARD), was held to address this challenge, and to identify the most suitable metrics for use in a salt marsh HEA.

II. Workshop Organization and Structure

The HEA Metrics Workshop sought to answer four questions: (1) What metrics or methods related to salt marsh ecosystem function are new or on the horizon that merit further evaluation?; (2) What are the limitations or advantages of metrics or methods related to salt marsh ecosystem function that have been used previously in HEA models?; (3) How does the idea of "baseline" and inherent ecological variability over short- and long-term scales affect the identification and utilization of measurements of ecological function in HEA models?; and (4) How does the regulatory context (Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) *vs*. Oil Pollution Act of 1990 (OPA)) affect the answers to the questions?

The workshop, held at the University of New Hampshire, consisted of plenary sessions where invited speakers discussed their experiences with HEA and gave their views on the challenges/solutions to problems related to its use. Breakout groups further discussed HEA and evaluated a number of metrics. There was a concerted effort to distribute affiliations and expertise across breakout groups to maximize exchange and ensure equal representation (Appendix A)[2]. The five "breakout" groups were given a list of approximately 40 potential marsh metrics that they scored on importance and/or relevance (Appendix B). The scores were tallied, and the metrics that scored the highest were then discussed and rated based on several different suitability criteria, including, measurement difficulty, cost, sensitivity, and accurate reflection of ecological services lost. Groups were encouraged to add metrics and suitability criteria as necessary. By the end of the workshop, each group developed a matrix of metrics, including documentation, of the most relevant HEA marsh metrics and their suitability for use

[2] For a complete list of workshop participants and affiliations go to http://www.crrc.unh.edu/workshops/hea_metrics/index.htm

under different conditions (http://www.crrc.unh.edu/workshops/hea_metrics/index.htm). This report summarizes the group discussions for appropriate HEA metrics, research recommendations, and general conclusions for the HEA approach developed at this workshop.

III. Results from Breakout Groups

Group A: General Summary

Group A spent a considerable amount of time conducting several parallel exercises. First, each metric (See Appendix B for the matrix of metrics) was discussed and classified using the "+1, -1, or 0" ranking system. Each group member was able to assign a "+1, -1, or 0" score to each metric. At the end of the exercise, the sum of the scores for each metric was computed. This exercise quickly sorted metrics by priority and thus determined where the group should spend most of its time and attention. As the ranking proceeded, a number of common HEA metrics fell into larger categories and were combined, including benthic community, plant community, exposure-response, water quality, avian/terrestrial animals, erosion/accretion, and threatened and endangered species. In order to identify the most important lumped metric categories, the group conducted a multi-voting exercise. Each group member was given 10 points to distribute among the lumped metric categories, and the categories with the most points was considered the most important. In general, the group felt metrics in the top three categories (benthos, plants, and exposure-response) were the most critical to HEA.

During these discussions, a number of items on the metrics list provided by the workshop organizing committee (Appendix B) were identified as important considerations in the injury assessment/restoration scaling process, but not HEA metrics *per se*. The non-metric items removed from consideration included, marsh edge, tidal creek morphology, current velocity, human use, human recreation, adjacent habitats, remote sensing, resource categories less directly related to marsh exposure, grain size and organic carbon content.

The group had an interesting discussion regarding the highest rated metric category, benthos. The group concluded that metrics reflecting benthic ***structure*** are generally better than benthic ***function*** metrics for the reasons given below. Despite the higher utility assigned to benthic structure metrics, the group felt there was still a critical need to link structure back to function and ecological service flows.

Reasons why benthic structure metrics may be better than functional/productivity metrics:

- Structural metrics are much easier to measure than functional.
- At high lethal doses, benthos will die and these diminished numbers may be more readily apparent in the structure metrics (number and density of species).
- At low doses, less sensitive species will "replace" the more sensitive species that have died. Again, this is more likely to be observed in structural metrics and less likely in productivity (function) metrics.
- At low doses of spilled oil, productivity metrics may be stimulated if microbes utilize the new carbon source.

Modifications to the List of Marsh Metrics and the Evaluation Criteria/Ratings

Major changes to the initial list of metrics resulted in lumping of metrics into the broader categories and removing some metrics from the initial list (Appendix B). The group made minor editorial changes to the metric titles; however, no changes were made to the 10 evaluation criteria.

The group discussed the natural variability (stochasticity) evaluative criterion and noted that it represents only 1 of the 3 major sources of uncertainty. The other two sources of uncertainty included: a) measurement error and b) model error. In the end, Group A decided not to partition out the uncertainties as separate sources of error. These uncertainties are embedded in other criteria (*e.g.*, measurement difficulty). Additionally, a group member suggested that using a single metric at multiple trophic levels is more defensible or robust than using multiple metrics at a single trophic level. Most group members agreed.

Group A developed a consensus weighting scheme in which each metric was evaluated against 10 evaluation criteria provided by the organizing committee (Appendix B). Each metric was given a score from 0 - 5 for each evaluation criteria. A weighted average was computed for each metric, with a higher score indicating that it was a good metric. The group had insufficient time to develop a ranking for every metric, however, the metrics were ranked according to weighted scores (Table 1).

Table 1. List of 10 marsh metrics evaluated in the matrix by Group A. These metrics are listed in rank order. Ranks with the same number indicate a tie for that ranking.

Final Description of Marsh Metric	Rank
Percent cover (live and dead)	1
Aboveground plant biomass/productivity	2
Exposure-response	2
Benthic structure	3
Benthic productivity/biomass	4
Fish	5
Belowground plant biomass/productivity	6
Water quality	7
Avian or terrestrial animal	8
Benthic epiphytes	*
Plant height	*
Plant species composition	*
Stem density	*

* = not ranked due to time constraints

New and Emerging Marsh Metrics and Research Needs Identified by Group A

Group A identified, “belowground plant biomass,” as a new and emerging marsh metric for HEA. While this metric is still embedded in the research and development community, work reported thus far appears promising (Lin et al. 2002; Turner et al. 2004). The group encourages practitioners to examine this metric in conjunction with the more traditional aboveground plant biomass when possible/feasible.

Unresolved Issues in Group A

- Group A would have liked "HEA metric" to be explicitly defined at the start of the workshop.
- Group A would have liked the organizing committee to more clearly describe the relationship and uncertainties associated with the "HEA metric" - ecological services linkage.
- Group A strongly urges practitioners to select metrics based on ecological services identified as lost/diminished as a result of the release of hazardous substances. Metric selection should also consider more broadly the processes of restoration scaling and long-term monitoring. Final selection of a metric or suite of metrics may be influenced by the fact that they could serve multiple functions.

Miscellaneous Items from Group A

Due to the wide range of toxicities associated with different classes of pesticides, this category of contaminants was considered too broad to be treated as a single unit. For example, selection of metrics would be quite different for a legacy insecticide such as DDT versus a more contemporary insecticide (*e.g.*, Fipronil) or an herbicide such as Glyphosate (active agent in "Roundup™." Consequently, Group A's deliberations ignored pesticides allowing the group to focus on metals, PAHs, and PCBs/dioxins/furans.

<u>Group B: General Summary</u>

The group began with an overview of HEA in general, its application, its limitations and briefly discussing as an overview the larger matrix of metrics (Appendix B), in part to assess individual level of understanding and experience and comfort with HEA and the exercise. Based on these discussions, two new criteria were added to the matrix: (1) metrics represent multiple functions, (later changed to "total services), and (2) state of knowledge and information about the metric. The group proceeded to do the preliminary prioritization exercise for the original 40 metrics, using a "+1, -1, or 0" ranking as a first cut, simplified way to identify the priority metrics. This exercise was done individually and then individual group member scores were entered into the spreadsheet and tallied and reviewed.

A thorough discussion of the metrics ensued, whereby metric definitions were clarified, and metrics were deleted, added or modified by grouping or separating (*e.g.*, tissue, sediment and water contaminant concentrations compared to thresholds were combined). The group discussed the differences in metric utility between their uses for injury assessment versus restoration scaling and long-term monitoring. Some metrics were determined to be primarily useful for restoration, while others were more useful or exclusively for injury assessment. Two corresponding columns were added to the evaluative criteria to reflect this distinction; however, there was not enough time to fill out these columns.

During these discussions, many group members changed their rankings based on clarification of definitions, new information learned in the larger group discussions and consideration of restoration versus injury assessment (*e.g.*, some metrics were ranked low because they were useful almost exclusively in restoration monitoring). Additionally, some metrics were ranked low because they were deemed to be tools rather than metrics (*e.g.*, imagery). Others were ranked low because they were more descriptive endpoints rather than actual metrics, but all recognized they might be useful to measure when associated with an actual metric evaluation. After a metric by metric review, discussion and re-ranking, Group B agreed to their top 10 metrics, which included abundance, species richness, density, and/or presence/absence of avian or terrestrial animals, threatened and endangered species, benthos, and fish and shellfish, as well as sediment toxicity, percent cover, aboveground vegetative productivity or biomass, habitat value/suitability, stem density, and concentration or presence/absence of toxics.

Once the most important (*i.e.*, highest scoring) marsh metrics were identified, the group spent the rest of the workshop evaluating their top metrics by criteria as listed in the matrix of metrics (Appendix B). The group's approach was slightly different from other groups in that Group B decided to evaluate criterion by criterion rather than metric by metric in evaluations and scoring (*e.g.*, they went down columns rather than across rows). This way, the criteria could be evaluated individually as they applied to each metric and relative perspective of how the criteria addressed each metric could be obtained. For example, measurement difficulty was the first criterion considered. These criteria were applied to all of the top metrics and developed a score for each metric using these criteria to fill in the table. It was very worthwhile to discuss the criteria before engaging in a rating so that all group members were considering the evaluation similarly.

Group B added three evaluation criteria: (1) representativeness of total services, (2) easily communicated, and (3) state of knowledge, however, there was not enough time to score the metrics based on these criteria. Sensitivity to PAHs was separated out from sensitivity to oils in the evaluation criteria, as it was determined that evaluation of effects is different for PAHs and bulk oil. The language in "metric useful for scaling" was changed to "metric accurately reflects restoration gains" to help focus the evaluation on restoration activities. Additionally, several modifications to the metrics themselves were made. The terrestrial animal metrics (abundance, species richness, density, or presence/absence) were separated out from the combined terrestrial-avian category. This was based on the assumption that the two categories (avian and terrestrial) would be so different in terms of scoring (based on assumed differences in assessment and restoration scaling methods) that they should be considered separately. In the end, they ranked equally.

Once the evaluation of the metrics by criteria was complete, the scores were summed and the metrics were ranked according to those scores. Table 2 contains the metrics with their relative ranking.

Table 2. List of 10 marsh metrics evaluated in the matrix by Group B. These metrics are listed in rank order. Ranks with the same number indicate a tie for that ranking.

Final Description of Marsh Metric	Rank
Sediment toxicity	1
Concentration or presence/absence of toxics (tissue, sediment and water column) exceedence of toxicity thresholds	2
Aboveground vegetative productivity/biomass	2
Percent cover (live and dead)	2
Habitat Value/suitability measured on a variety of factors including refuge and feeding	3
Benthos abundance, species richness, density, or presence/absence (benthic macroinvertebrates or benthic infauna)	4
Fish and shellfish abundance, species richness, density, or presence/absence	5
Threatened and endangered species abundance, species richness, density, presence/absence	6
Terrestrial animal abundance, species richness, density, or presence/absence	7
Avian animal abundance, species richness, density, or presence/absence	7

High Priority Research Needs Identified by Group B

Group B identified research needs associated with the twelve (12) HEA metrics fully evaluated in the matrix. Additionally, Group B undertook a brainstorming activity to identify other areas of research that would be applicable to improving HEA.

- Research impacts to algae (composition, diversity, biomass) due to contamination.
- Research on sensitivity and abundance of epiphytic invertebrates.
- Development of remote sensing as a tool for more accurately measuring the metric of shoreline vegetation die-off, degree of oiling, and other endpoints.
- Research on natural versus created marshes in multiple regions comparing specific metrics.
- Research to develop an index that combines multiple measurements into a single endpoint that relates to marsh services.

Unresolved Issues Discussed by Group B:

- Group B spent time every day considering "what is a metric," especially in the context of HEA and marshes, and assessment versus restoration.
- The "habitat value/suitability" measured on a variety of factors including the "refuge and feeding" metric rated highly in Group B, but this was probably due to the fact that this metric does not currently exist as a single metric, and in reality would represent multiple endpoints. While the group was unable to determine what would be measured specifically and how it could be applied, in general, this metric was favored because it would link multiple measurement endpoints together, and therefore potentially be more reflective of marsh ecological services than a single metric.
- Often the group debated the utility of metrics in assessment versus restoration monitoring. It was unclear if the metric needed to be used for both activities.
- The disparity (or perceived disparity) and therefore importance in metric ranking between what the public values as marsh services and what scientists value as ecologically

important was never resolved, but discussed often. How important should the consideration of what the public values factor into this analysis?

Miscellaneous Items from Group B:

- The group discussed that some metrics are applicable for either restoration or injury assessment, but not universally. Additionally, some metrics while useful for oil spill assessment were not useful for more chronic contamination scenarios. This was not reflected well in the matrix, but was a subject of frequent discussion. The collective suite of vegetation metrics is one such example. It was acknowledged that even though aboveground vegetative biomass and percent cover ranked highly, they would not be particularly desirable metrics to use to determine service losses at a chronic waste site due to their lack of sensitivity. However, it was acknowledged that if *Spartina* level effects were observed at a waste site, then ecological services were significantly impacted. The vegetative metrics would, however, be a useful metric for marsh restoration.

- The residence time of receptor species would greatly influence rankings.
- The group concluded that there is not a "perfect" metric, and that depending on the release scenario and the needs of the team, multiple metrics may be necessary.
- The group agreed that HEA as a tool is a useful way to bring data together, and the group considered it a 'rigorous' tool, especially in a cooperative scenario.

<u>Group C: General Summary</u>

Group C decided to spend time modifying the initial matrix of metrics (Appendix B) that was provided before filling in the matrix. The group generally agreed to keep the evaluation criteria intact, although several additional evaluation criteria were added as the workshop progressed. Near the end of the first day, the group elected to employ the "+,1 -1, 0" voting technique to reach consensus on which metrics deserved the most discussion. Group C did not fill out the matrix on the first day but the discussions were highly energetic with a high degree of candor.

After the first day of group discussion, the original list of 40 metrics was reduced to a list of 21 metrics. The number of metrics was reduced by combining metrics with other metrics or deleting them from further consideration based on the results of the "+1, -1, or 0" technique and the group's consensus that the metrics would not be suitable for HEA. One marsh metric was added, "food web modeling," but was later sub-divided into two categories that reflected two primary types of models (*i.e.*, bioenergetics and contaminant bioaccumulation through the food web).

On day 2, the group decided to eliminate the marsh metric "human use metrics" from further consideration. The group's rationale for not addressing the human use metric was that human use losses are typically calculated with different models than HEA. After more voting techniques were employed, the remaining metrics on day 2 were narrowed down to eight. A final list of the eight marsh metrics that were fully addressed by Group C is provided in Table 3. These eight marsh metrics had the highest ratings by Group C during both voting exercises.

On the second day, the group elected to use the multi-voting technique to prioritize its effort on the matrix. The multi-voting technique (individual ranking and group ranking) was conducted first to make sure the two voting methods achieved the same results and because the group felt it was important to re-calibrate after the plenary discussions the previous afternoon. After the multi-voting exercise, eight metrics (Table 3) had the highest scores and the group proceeded to fill out the matrix for three of the eight metrics. The group assigned ratings to each cell of the matrix as cells were filled out and each rating was assigned by group consensus. Consensus on ratings typically was obtained relatively easily, but a few of the ratings were discussed in more detail. Despite minor disputes over terminology and matrix content, good progress was made on the second day because the group proceeded from modifying the matrix structure to capturing input from group members on the eight highest-rated marsh metrics.

On the third day of the workshop, Group C was focused on providing detailed matrix entries for the remaining marsh metrics that scored the highest during the multi-voting exercise, as well as the new food web modeling metrics. At the conclusion of the third day, the group felt strongly that excellent progress had been made on the highest priority metrics and research needs had been identified. The Group C matrix was completed for eight priority marsh metrics.

Summary of Modifications to Evaluation Criteria and Ratings by Group C

After initial discussions on day 1, Group C decided to leave the evaluation criteria and rating system largely intact. This decision was made primarily because time was limited following a long discussion that was focused on re-working the list of marsh metrics. Overall, the group had some trouble coming to consensus on the definition of several evaluation criteria and did not successfully identify a complete list of assumptions that correlated with each of the evaluation criteria. The difficulty in coming to consensus on the matrix structure, however, did not translate into difficulty filling out the matrix or assigning ratings. As the group went through the exercise of evaluating the marsh metrics, many of the terminology issues associated with the evaluation criteria became less important when ratings were considered.

On day 1, Group C added evaluation criteria: time scales, ecological services (direct), and ecological services (indirect). On the second day, the three criteria additions were changed to time scales, research needs, and usefulness for restoration planning and success monitoring. The evaluation criterion “usefulness for restoration planning and success monitoring” was added because the group members felt that many of the original marsh metrics were not suitable as HEA metrics, but could serve as data inputs that fed into the evaluation of whether a restoration project was successful at achieving ecological function. On day 3, the criterion “time scales” was abandoned because group members preferred to comment on the temporal considerations related to a marsh metric within a matrix cell instead of having it as a stand-alone criterion. Table 3 lists the metrics selected by Group C in rank order.

Table 3. List of 10 marsh metrics evaluated in the matrix by Group C. These metrics are listed in rank order.

Final Description of Marsh Metric	Ranking
Aboveground vegetative productivity or biomass (plant height, stem density, percent cover); species composition	1
Benthic and epi-benthic abundance, species composition, species richness, density, or presence/absence (could be benthic macroinvertebrates or benthic infauna); individual growth	2
Water (column, porewater, ground water), tissue (lipid) and sediment (OC and grain size, redox potential) concentrations or quantification of contaminants of concern	3
Bioassays - lab or field (sediment, water)	4
Avian, reptiles, amphibians, mammal field abundance, species composition, species richness, density, or presence/absence; growth, productivity of nest; behavior	5
Fish and shellfish field abundance, species composition, species richness, density, or presence/absence; individual growth/reproduction; behavior	6
Food web modeling - energetic flows	7
Food web modeling - food web contaminant transfer	8

New and Emerging Marsh Metrics Discussed by Group C

The group spent several hours over the course of the workshop thinking about new or emerging marsh metrics. Group C identified food web modeling and monitoring of *Uca spp.* as two marsh metrics that were not included on the original list. The group also spent time thinking about ways to integrate multiple marsh metrics into NRDA to more fully capture ecological function. Some of these small group discussions had a nexus to the larger workshop discussions of indices of habitat quality or cases where multiple marsh metrics have been used in NRDA. The group generally agreed that any single marsh metric does not adequately capture the full range of services that are typically associated with salt marshes, but some metrics do a better job than others. More importantly, the group agreed with the idea discussed in the larger group setting that the metric(s) chosen during NRDA should reflect the affected ecological service or range of services that stakeholders and/or decision-makers are concerned about.

Group C felt that several of the original marsh metrics could be evaluated using a GIS platform to act as a “new” metric for HEA. Group C termed this group of metrics “habitat modifiers”. Habitat modifiers identified by Group C that can be integrated with a GIS to indicate a habitat’s value include:

- Habitat connectivity;
- Landscapes adjacent to the marsh of interest;
- Amount of marsh edge;
- Area of tidal creeks and sloughs;
- Native/invasive species composition; and,
- Presence/absence of threatened and endangered species.

High Priority Research Needs Identified by Group C

Group C identified research needs associated with each of the eight marsh metrics fully evaluated in the matrix. Additionally, Group C undertook a brainstorming activity to identify other areas of research that would be applicable to improving HEA.

- Use of *Uca spp.* as useful marsh metric.
- Use of a habitat quality index approach during HEA analysis (using landscape-level factors and GIS tools); how do you take a qualitative factor like habitat connectivity and translate that into marsh service?
- Evaluating aboveground biomass for other common marsh species (*e.g.*, *Juncus spp.; Salicornia spp.*) not just *Spartina spp.*
- Evaluate link between marsh restoration and fish utilization; How does this translate into production?
- Long-term evaluation of mature restoration sites to ascertain whether projects match HEA projections (in both oiled and hazardous waste sites).
- Benthic species sensitivity distribution for different chemical classes; productivity/biomass (P/B) ratios need more research to validate approach; relative importance of trophic conversions (size dependency, carbon quality); prey size important for evaluating food resources.
- Benthic P/B ratios need more validation.
- Values needed for trophic conversions related to factors such as size dependency, prey size, etc.
- Service loss linkages between contaminant mixtures and contaminant bioavailability.
- Amphibians are a group of animals that are very under-studied in the NRDA context.
- Develop species sensitivity distributions for more chemicals or groups of animals that are locally or regionally appropriate.
- In order to improve food web models, understand flexibility of consumers to shift feeding selections.
- Incorporating laboratory toxicity information (especially sublethal endpoints) for fish, turtles, birds, amphibians, and reptiles.
- Effects of climate change or sea-level rise on scaling restoration projects.

Unresolved Issues Discussed by Group C

- Group C spent a portion of the first day discussing "What is a metric?" The group discussed that a metric generally becomes more valuable if it connects with multiple parts of the NRDA process, such as injury assessment, restoration scaling, and restoration monitoring. For any given metric, the lack of agreement on a performance standard by a responsible party or potentially responsible party and the Trustees is a big hurdle to overcome. A metric has a higher value if it is connected to multiple natural resource services generated by salt marsh habitat.
- Group C had technical discomfort with lumping or splitting marsh metrics or evaluation criteria together. Due to time constraints, the group combined many items together that normally would be addressed separately. An example is the various contaminant classes (*e.g.*, inorganics or other persistent chemicals). Group C agreed that criteria for one

marsh metric may have a different rating, ranking, and/or consideration, depending on which chemical of concern.
- In an NRDA where Threatened and Endangered (T&E) species are involved, T&E species issues will have to be faced by all parties. Therefore, little group time was spent on this metric although all group members acknowledged the potential for this issue to drive the entire NRDA process.

Miscellaneous Items from Group C

- Multi-voting and "+1, -1, or 0" voting results were very congruent among group members, resulting in similar ordinal rankings for the marsh metrics.
- Group C agreed that human use models and Resource Equivalency Analysis are separate processes and therefore the metrics typically associated with these models were not discussed in detail.
- One group member strongly expressed a desire that species richness should not be considered a metric since it is often mis-used, not calculated correctly, or not compared in a statistically rigorous fashion to baseline or reference areas.
- Food web modeling could be considered a tool instead of a metric, but the concept scored higher than many other marsh metrics. Group C talked in detail about the food web modeling concept and its applicability to HEA, especially in linking sediment contamination to higher tropic level effects.

Group D: General Summary

On day 1, the group discussed individual metrics, as needed, to clarify any differing interpretations within the group. The group then discussed the process and how best to tackle the charge that had been given to complete the matrix. Consensus was reached that the group would start by going through each metric, hold a brief discussion for clarifications as needed, and then, individually, apply a "+1, -1, or 0" rating. The group then started to fill in the matrix by first addressing the metrics that received a positive rating from the majority of the group.

On day 2, Group D began the morning breakout session by revisiting the goals of the week, and highlighting metrics that were edited on day 1. With the matrix sorted by metrics receiving the highest rating from the previous day and descending to metrics that received all 'minuses,' the group continued filling in the matrix by addressing the criteria for one metric at a time and moving down the metrics. During this time, individuals were free to change their rating. The group identified metrics that were deemed not suitable for HEA. There were several reasons why a metric was not suitable, including metrics that were supporting parameters to other metrics (*e.g.*, water quality measurements), not scalable as a HEA parameter, or more appropriate as restoration success criteria. A metric was removed from the list only if it was absorbed or 'lumped' into another metric. At the end of the day, the group had completed the matrix criteria for metrics that received 7 out of 7, or 6 out of 7 "plus" votes from the group and had completed the assumptions for every metric in the matrix.

On day 3, each person's multi-vote was added to the matrix. The matrix was then re-sorted based on the total multi-voting scores. For the most part, metrics receiving no points from the multi-vote had already been marked as not suitable for HEA. Seven metrics emerged with a multi-vote of more than 15 points and having received votes from 3 or more group members. At day's end, 12 metrics were deemed suitable for use in a HEA (Table 4). The group finished the matrix for the metrics deemed suitable for HEA.

Summary of Modifications to Evaluation Criteria and Ratings by Group D

Group D decided to adopt the proposed evaluation criteria and rating system (Appendix B), but added three new criteria: importance to CERCLA/OPA, importance to injury, restoration, and/or long-term monitoring, and regional significance. Due to time constraints, these additional criteria were not given numeric ratings as were the original 10 criteria.

Summary of Modifications to Marsh Metrics by Group D

By the end of the workshop, Group D determined that 12 of the original 40 metrics were suitable for HEA. Five of these 12 metrics were either re-worded, a grouping of several original metrics, or added by the group. The rest of the metrics were deemed either not scalable, more appropriate indicator of restoration success, or, simply, not practical for HEA calculations. Based on the results of the multi-vote, Group D decided that the first 7 metrics described in Table 4 were the most important marsh HEA metrics to consider.

Table 4. List of 10 marsh metrics evaluated in the matrix by Group D. These metrics are listed in rank order.

Final Description of Marsh Metric	Ranking
Aboveground vegetative production, biomass, species composition (includes invasives & exotics) &/or percent cover (*e.g.* stem density, height, etc.)	1
Benthic infaunal abundance, species richness, density, presence/absence, species composition (includes invasives & exotics) &/or percent cover (could be benthic macroinvertebrates or benthic infauna)	2
Belowground vegetative production or biomass	3
Sediment contamination	4
Sediment toxicity	5
Fish and epibenthic invertebrate abundance, species richness, density, presence/absence, species composition (includes invasives & exotics) &/or percent cover	6
Faunal tissue contamination	7
Habitat value for feeding or refuge	8
Percent survival flora	9
Threatened and endangered species abundance, species richness, density, presence/absence	10
Algae	11
Exacerbated rate of marsh horizontal erosion or accretion	12

New and Emerging Marsh Metrics Discussed by Group D

Group D agreed that two metrics should be identified as emerging metrics: habitat value to feeding or refuge, and algae parameters such as sensitivity, composition and biomass. For the former, the group agreed that this metric would provide a good measurement of physical, chemical and biological disturbances. However, the current methods available for measuring such a metric are complex and/or expensive, hence the low ranking. For algae, the group agreed that algae could be a good indicator of marsh health given its prevalence in marshes all over the country and its sensitivity to contaminants, particularly oil. However, the group acknowledged that little baseline data are available for algae metrics and there was a general uncertainty about how best to measure them to reflect service loss.

High Priority Research Needs Identified by Group D

Group D identified research needs associated with each of the eight marsh metrics fully evaluated in the matrix. Additionally, Group D undertook a brainstorming activity to identify other areas of research that would be applicable to improving HEA.

- Defined method for measuring ecological service on habitat scale.
- Algae parameters as an emerging metric. Measurement protocols need development using percent loss of primary productivity as injury criteria.
- Develop remote sensing techniques as a HEA metric tool.

Unresolved Issues Discussed by Group D

- Sediment toxicity – there was a lot of discussion about how it related to service loss. Several members of the group felt that it is not an indicator at higher trophic levels since it requires modeling generalizations and assumptions.
- Is it realistic to rely on one metric to represent marsh service losses, or is it better to use a suite of metrics?
- Does the best metric suite both injury and restoration scaling? Separate metrics can be used that have a common measurement of service loss.
- Threatened and Endangered Species – Should a HEA be used here? The group discussed whether the local extinction of one T&E species on a marsh accurately measures the overall service loss to that marsh. One argument was that the primary function of that piece of marsh was to preserve that T&E species. The other argument was that perhaps it gives a much larger credit to the T&E species and ignores major marsh functions.

Miscellaneous Items from Group D

- It was interesting to note that the “habitat value for feeding and refuge” metric rose to the top of the multi-vote ratings due to one 10 point vote. This may be useful to evaluate/caveat when analyzing the multi-vote scores.
- Habitat value – The group did not fill out the matrix because it felt that the assumptions, comments and measurement criteria would be reiterated throughout the rest of the criteria.

<u>Group E: General Summary</u>

Group E began its process with a conceptual overview and review of the HEA process for less-experienced group members. Some observations:

- HEA was characterized as environmental science melded with negotiation to reach agreement about service loss in an affected habitat.

- Structural and functional measures/metrics are used as proxies or surrogates for service loss.
- Each HEA is different, tailored to a particular incident.

The group was asked to review the list of 40 metrics and, without modification, assign a "+1, -1, or 0" score to indicate the perceived value of the metric for inclusion in the matrix. The "+1, -1, or 0" votes of the seven group members were numerically tallied into a single value to give the initial screening value for a given metric. This allowed the group to quickly identify the metrics judged to be most useful or promising. Metrics for which the rank number was low due to conflicting opinions or perceptions were also noted.

By the end of day 1, Group E had completed the initial review of the marsh metrics listed in the provisional matrix. Highest screening values were generally assigned to familiar vegetative measures of marsh plants. Lower screening values were generally assigned to parameters judged to be more peripheral and less directly linked to structural or functional biological aspects of the habitat. The group recognized the potential importance of these mostly physical factors in driving biological characteristics of marsh habitat, but considered ecological structure and function to be the critical link to marsh services.

Some of the candidate metrics (tidal dynamics, water depth, water source identification & hydrologic exchange, and wave energy identification) were deemed by the group to be more appropriate considerations for restoration-type activities. A few metrics (habitat value, human uses) were not scored because they were judged to be closer to marsh services, rather than metrics.

It was clear from the initial screening exercise that a category of direct plant measurements (survival, plant height, percent cover) were considered to be important metrics; the more general and less readily quantified aboveground vegetative productivity was also included, although this was later subdivided into productivity and biomass metrics. The group noted that seasonality was an additional consideration that needed to be factored in to any of these direct plant measurements when considered for use. There was also consensus agreement that some of the listed "metrics"—sediment organic carbon or grain size, for example—might more appropriately be considered to be *modifiers* to metrics, vs. actual metrics that provided real linkage to marsh service gain or loss.

The concept of "marsh metrics linkage to service gain or loss" emerged as an important guiding consideration for Group E, and remained a thread through its remaining discussions during the workshop. By itself, the term "marsh services" is somewhat vague and difficult to consider in a quantitative or semi-quantitative process like HEA. However, the group realized the relevance of Charles "Pete" Peterson's identification of eight specific services provided by marshes, and these provided a framework for thinking about linkages:

- Habitat and food web support;
- Buffer storms (resiliency);
- Shoreline stabilization;
- Hydrologic processing (storage);
- Water quality;
- Biodiversity preservation;
- Carbon storage; and,
- Socioeconomic services to humans.

During the discussions about the candidate metrics, Group E made some modifications both for clarification and to improve the perceived utility and relevance of the metrics. Aboveground vegetative biomass was added as a companion measurement to belowground vegetative biomass, and sediment toxicity was added as an empirical companion measurement to sediment contamination. A new metric, contaminant chemical profile of water or porewater, was added because the listed parameters of dissolved oxygen and salinity were thought to be less important than contaminants. A new metric was created that included all plant-specific measures into a single value, weighted sum of % cover, height, density and species diversity.

Some concern was expressed in the full workshop plenary about "lumping" of metrics into a weighted sum. The basis of the concern was the anticipated difficulty to be encountered during the actual weighting of component measures. However, one HEA practitioner within Group E opined that if agreement could be reached on the component measures, weighting would easily follow.

Group E began its second day of work with a fairly lengthy discussion about the **relationship between structural and functional metrics**, and how both of those link to service or services provided by a marsh. Interrelationships between structure, function, and service were discussed in some detail.

Group E spent a good portion of the second day reviewing the criteria for evaluating metrics and documenting definitions and assumptions. In light of the considerable discussion about metric type, an additional column was appended to the matrix for noting whether a given metric was considered to be structural or functional. Also, as a result of group discussions about the differences between CERCLA- and OPA-based assessments (*e.g.*, differences in time scales, type of contamination, nature of exposures, etc.), the "baseline data available" criterion was split into CERCLA and OPA subcategories.

One new metric was suggested over the course of the discussion: food web structure. One new criterion was proposed: which ecosystem function does this metric help to assess? The discourse on research reflected the group sentiment that, by and large, the original list of metrics provided sufficient scientific grounding for the HEA process. However, there seemed to be near-universal agreement both within Group E and across the workshop at large that connections between marsh metrics and marsh services should be strengthened. In Group E's discussions, one group member described a marsh assessment approach based on the Global Programme of Action Coalition (GPAC) protocols, which evaluates marsh recovery using many metrics on a long time scale—this index is called Relative Performance Index (RPI).[3] It was suggested that this might provide a template for application of multiple habitat metrics to evaluate status and trends within marsh areas of interest. Table 5 represents the marsh metrics evaluated by the group.

[3] http://marine.unh.edu/jel/tidalmarsh_ecology/research.htm

Table 5. List of 10 marsh metrics evaluated in the matrix by Group D. These metrics are listed in rank order. Ranks with the same number indicate a tie for that ranking.

Final Description of Marsh Metric	Rank
Sediment grain size	1
Organic matter content	1
Sediment contamination	2
Aboveground vegetative biomass	3
Weighted sum of % cover, height, density and species diversity	3
Aboveground vegetative productivity	4
Percent cover (live and dead)	4
Stem density	5
Plant height	6
Contaminant chemical profile of water or porewater (*e.g.*, PAHs)	7
Percent survival of adults or seedling survival	8
Threatened and endangered species abundance, species richness, density, presence/absence	9
Sediment toxicity	10
Belowground vegetative biomass	11
Belowground vegetative productivity	11

High Priority Research Needs Identified by Group E

Group E spent a considerable amount of time discussing research to facilitate the development of more effective marsh HEA metrics. Although the group had concluded early on that it was unlikely that a "perfect" metric existed for marsh HEA activities, there was consensus that scientific validation of existing preferred metrics was highly desirable in order to lend further weight to the HEA process itself—as well as its outcomes, *i.e.*, research is necessary to support the selection of HEA strategies. Research needs included:

- Focus on injury, damage assessment, and restoration; and less focus on long-term monitoring aspects.
- Better ways to relate metrics to service gain/loss; reduce divergence between service and metric.
- Focus on higher-level metrics or measures with intent that they capture a larger picture.
- Investigate possibility of setting aside different types of marshes—controlled injury and measures of recovery. Desirable to manipulate (impact) a reference marsh to evaluate recovery of metrics.
- Important to prioritize legal imperative for linking injury to releases and damage claim processes (link cause to effect to compensation).
- Increase scientific rigor of metrics (must be scientifically-defensible because of enhanced role of and increased scrutiny by third parties, *e.g.* NGOs).
- Hindsight: suggest evaluating the body of settlements through HEA, particularly non-controversial ones; and then conduct rigorous science to determine, *i.e.*, did we get it right or not?

Unresolved Issues Discussed by Group E

- There was consensus on the idea that validation of existing metrics would strengthen the HEA process and improve the perceived legitimacy of outcomes; however, there was also recognition that validation can be both difficult and expensive. One group member cited the "cost-accuracy-resources" triangle, which illustrates that it is generally possible to satisfy no more than two of the three in any given research or monitoring effort.
- In the case of multiple responsible parties and time horizons, what is the best way to allocate injury and restoration?
- HEA remains a process of technically-based social discourse, one that begins with scientific observation in the field and ends with humans negotiating in a room; is a reasonable goal for improving HEA & HEA metrics to simply put more information and synthesis at our fingertips?

Miscellaneous Items from Group E

- "+1, -1, 0" voting served two purposes on the first day of group interaction: it was an effective screening tool for rapidly introducing and reviewing the list of metrics; and it also acted as a kind of "icebreaker" for engaging group members.
- Group E noted three characteristics of a good metric: (1) the metric changes over time with restoration and recovery; (2) the metric does not result in more than 100% injury and; (3) the metric does not result in double counting.
- Some items to consider during the emergency response phase of an incident, in anticipation of HEA: start ephemeral data collection early; designate and reserve personnel resources for conducting NRDA; factor time and personnel constraints into selection of metrics.
- Some factors that can potentially facilitate successful HEA experiences: early agreement between Trustees and the RP on injured resources and metrics to be used as proxies for ecosystem services; values with defined uncertainties can be beneficial to moving toward restoration; discussions might be easier assuming 100% service loss, but 100% loss rarely occurs.
- An experienced practitioner of HEA concluded near the end of the workshop that for all its identified flaws, HEA provides a more scientific basis for determining damage and compensation than has previously existed; pointed out that Clean Water Act compensation is defined in a very arbitrary way, and at least now there is a little more objectivity.

Conclusions

In December 2007, the Coastal Response Research Center brought together 36 natural resource professionals representing a wide variety of disciplines, sectors and agencies for the NOAA-CRRC HEA Metrics Workshop held at the University of New Hampshire. The workshop was structured around 5 breakout groups with 6-8 participants in each group. Each group was asked to independently evaluate marsh metrics and answer the four questions posed at the beginning of the workshop: (1) What metrics or methods related to salt marsh ecosystem function are new or on the horizon that merit further evaluation? (2) What are the limitations or advantages of metrics or methods related to salt marsh ecosystem function that have been used previously in HEA models? (3) How does the idea of "baseline" and inherent ecological variability over short- and long-term scales affect the identification and utilization of measurements of ecological function in HEA models? (4) How does the regulatory context (Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) *vs*. Oil Pollution Act of 1990 (OPA)) affect the answers to the questions? For three days, the participants deliberated marsh metrics related to HEA, suggested improvements to the state of the practice, documented strengths and weaknesses of individual marsh metrics, and provided input regarding how an individual or groups of marsh metrics were related to ecological services. Over 800 hours of combined thought and discussion by these experts resulted in important insights that are summarized in this concluding section.

This section is organized into five sub-sections. The first sub-section summarizes the advantages and limitations of marsh metrics currently used in HEAs. The next sub-section compares and contrasts the use of HEA metrics for oil spills (under OPA) and hazardous waste sites (under CERCLA). The third sub-section examines the relationship between HEA metrics and: (1) the concept of "Baseline" and (2) the influence of natural variability (stochasticity). The fourth sub-section identifies new and emerging HEA metrics that were identified during the workshop. And the final sub-section summarizes some unexpected but highly valuable insights that emerged from the groups asking some fundamental questions about HEA metrics.

Advantages and Limitations of Marsh Metrics Currently Used in HEAs

The Organizing Committee gave each group a list of 40 potential saltmarsh HEA metrics and a list of 10 criteria for evaluating the metrics (Appendix B). It was made clear to the groups that this matrix of metrics was a suggestion only and that they were free to add/delete as they saw fit. With minor edits, all the groups accepted the suggested matrix of metrics as a starting point for evaluating and ranking metrics. Almost all of the groups treated the list of 40 marsh metrics and 10 criteria in a similar fashion. First, they placed the metrics into broad categories that generally mirrored biological resources: (in no particular order) plants, benthos, sediment toxicity, fish/shellfish, and contaminant exposure-biological response. Next, groups identified items that were not metrics *per se* but were important considerations in the injury quantification/restoration scaling process (*e.g.*, remote imagery, water depth, sediment grain size). Third, groups identified new and emerging metrics (see "New or Emerging Metrics" sub-section below).

A significant outcome of the workshop was that there was congruence among participants regarding the top-ranked marsh metrics for HEA and in the kind of criteria NRDA practitioners should use to evaluate those metrics. The top-ranked metrics are ones that have been associated with NRDA under OPA and CERCLA for over 10 years. This similarity in metric rankings among the groups may be driven by two factors: (1) the workshop participants ranked certain metrics highly because they have a collective experience with them or (2) the top-ranked metrics are indeed the most suitable for use in HEA. Following the workshop, the Organizing Committee discussed these two possibilities and concluded the similar rankings were an affirmation of the current suite of metrics in use today. This conclusion rests on the observations that: (1) workshop participants represented such a broad perspective (government, industry, academia) and (2) none of these participants expressed an opinion that could be construed as contrary to the affirmation conclusion. This conclusion is further strengthened by the many anecdotal remarks at the end of the workshop that the basis for selecting and using our current suite of marsh metrics appears technically sound.

Although fully evaluating the advantages and limitations of each metric is beyond the scope of this concluding section, several generalities emerged among the top-rated marsh metrics.

- A marsh metric that is easy to measure is highly valued even if the relationship between the metric and ecological services is open to broad interpretation by NRDA practitioners.
- Marsh metrics that are applicable to conducting injury assessment and monitoring restoration success are not necessarily more advantageous because service flows could potentially differ during the injury assessment and restoration phases. The opinions of the NRDA practitioners for a particular waste site or oil spill significantly influence the "value" or perceived advantages/disadvantages of a particular metric.
- Not unexpectedly, most of the top-rated marsh metrics have either legal or technical precedent in NRDA cases or have a more developed technical framework for linking measurement endpoints to service flows. Marsh metrics previously considered in detail by practitioners across the country have a significant advantage over those that have not. The detailed comments by the five groups on a wide variety of metrics suggests that widespread use or acceptance of new or emerging marsh metrics may have to overcome considerable scientific and legal hurdles before widespread acceptance in the NRDA process.
- Marsh metrics that require models for interpretation or correlate to injury or recovery across trophic levels typically result in elevated scrutiny by NRDA practitioners, potentially resulting in a cost disadvantage.
- Metrics that intersect with threatened and endangered species, recreation and human use, and marine mammals are typically considered outside the HEA using other assessment tools (Figure 1). Several groups noted that metrics for threatened and endangered species could be used more effectively in an index that includes information on habitat characteristics and animal behavior. Some groups recognized the legal requirements to consider threatened and endangered species but questioned their importance during quantification of ecological service flows.
- Some marsh metrics were noted as more applicable to either waste sites, chronic releases, or oil spills, but usually not to all three (see next sub-section). For example, a metric such as sediment toxicity could be applicable to each kind of scenario. Broad applicability of sediment toxicity to multiple frameworks was considered an advantage by several groups. Conversely, several groups also noted that a major disadvantage with the sediment toxicity metric was establishing the link between sediment toxicity and service flows. The sediment toxicity example is illustrative because a major outcome of the workshop was that major trade-offs were almost always identified when marsh metric(s) are used in the HEA model.

Overall, the wide variety of contaminants and their respective modes of action addressed during NRDA prevented groups from identifying detailed advantages and disadvantages associated with a particular contaminant under the OPA and CERCLA frameworks. Each of the groups was hesitant to broadly associate their technical input with a general class of chemicals.

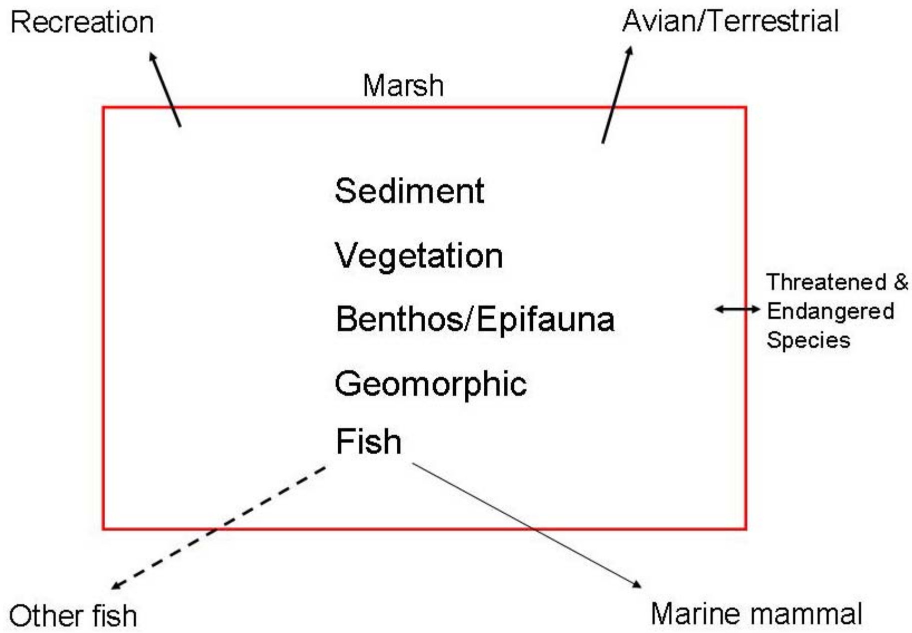

Figure 1. Relationship of resource categories in a marsh that is typically applicable to marsh metrics for HEA. Injuries to resource categories outside the box are typically addressed with other techniques. The marsh ecosystem is denoted by a box in this figure. The conceptual diagram originated from a group at the workshop.

Influence of OPA and CERCLA on Marsh Metrics Selection for HEA

During the plenary presentation outlining the goals and objectives of the workshop, the Organizing Committee acknowledged that a technical evaluation of a marsh metric is greatly dependent on whether a NRDA was being conducted under OPA or CERCLA. Overall, the groups did not spend much time addressing this issue, choosing instead to focus on more fundamental questions related to HEA and accomplishing other objectives. During large group exercises, multiple participants pointed out that primary differences using HEA for waste site assessments compared to oil spills are: (1) time scales are longer, (2) there is a broader swath of chemicals, and (3) biological effects may be much more varied. Many of the top-rated marsh metrics are those that have been used in NRDA activities under both regulatory frameworks for many years. Several participants strongly noted that linking injury and ecological service flow to a specific discharge or set of chemicals is important and a legal necessity under both frameworks.

Evaluating Baseline and Ecological Variability for HEA Marsh Metrics

NRDA regulations require a consideration of "Baseline". The Organizing Committee asked each of the groups to consider baseline in the context of selecting HEA metrics and inherent ecological variability. The groups were also asked to think about how long-term monitoring efforts can better help define baseline and reduce or at least quantify environmental variability. The groups addressed these issues from a process and technical perspective during the workshop.

From a process perspective, the idea was expressed that NRDA practitioners working together should first define what kind of uncertainty and level of uncertainty is acceptable so that agreements can be reached based on technical details and then move on to restoration activities without revisiting the uncertainty questions. Participants noted that uncertainty is a broad term with three major sources: (a) measurement error, (b) model error, and (c) stochasticity. Marsh metrics for HEAs with well-defined uncertainty were considered more valuable because of their potential to move the NRDA process forward to restoration. From a technical perspective, several groups noted that finding suitable reference site(s) as a surrogate measure for baseline is a challenge in many areas of the country resulting in a technical constraint that is often difficult to overcome. Several participants noted that this is especially problematic in urban areas. Many of the groups noted that landscape-level considerations (*e.g.*, scale, or adjacent habitats) should be considered when NRDA practitioners attempt to resolve issues associated with baseline and environmental variability.

Over the course of the workshop, each of the groups as well as individual participants offered suggestions for addressing baseline and environmental variability in the context of HEA. Not all participants supported the following list of technical suggestions many of which spill-over into the next sub-section.

- Verify assumptions for reference sites that apply to marsh metrics used in HEA.
- Locate or undertake statistically valid monitoring efforts to verify recovery rates used in HEA.
- Place a high value on measuring a few lower trophic level marsh metrics that are representative of the entire ecosystem rather than trying to measure separate metrics for the majority of important services. That is, keep the number of metrics small, simplify the problem, and use those marsh metrics that truly serve as proxies for ecosystem services.
- Consider using a sum of marsh metrics to determine injury and service loss.
- Integrate landscape functions into marsh metrics for HEA (*e.g.*, value of connectivity and adjacent habitat in a habitat trade-off ratio).
- Evaluate habitat recovery curves from past projects to verify projections.
- Research should target reducing environmental uncertainty of marsh metrics for HEA over season, location, age, time, and site-specific heterogeneity. For marsh metrics involving vegetation, other dominant species should be studied in addition to *Spartina alterniflora* and *S. patens*.
- Rely on regional or long-term datasets that document reference conditions to a greater degree during NRDA cases.

New or Emerging Marsh Metrics

The Organizing Committee asked each group to identify potentially new and emerging metrics and areas of research that would advance our understanding of HEA metrics. A significant outcome of the workshop was that the five groups identified more than 25 new and emerging metrics or research needs. These recommendations were highly diverse and ranged across trophic levels, measurement difficulty, and cost. Some examples include: belowground plant biomass or productivity, fiddler crab density (*e.g.*, *Uca spp*.), food web modeling for energy flow, nutrient cycling, and contaminant trophic transfer, and using microalgae to generate biomass or primary productivity estimates. A common thread among the new and emerging metrics is the need to establish a more robust link between the metric and ecological service flow(s). More than one group highlighted the need to incorporate emerging remote sensing and GIS technologies to improve the accuracy and precision of HEA metrics.

Using indices of multiple metrics to estimate resource losses and gains with HEA was an embedded theme in the new and emerging metric discussion. Several participants and invited speakers provided examples of indices that combined multiple marsh metrics over long time scales to evaluate ecosystem function and resolve liability. Several participants voiced their concern that the process of weighting multiple marsh metrics for HEA in an index can be semi-subjective, time-consuming, and needs to be examined in more detail. Other participants indicated that weighting marsh metrics for HEA is easier when there is consensus on the purpose and components of the index. Indices that may be appropriate for use at regional or national levels were not discussed in detail, although several participants identified the topic of using indices in HEA as a major research need. Multiple groups remarked that GIS platforms are appropriate to pair with habitat indices or landscape-level information about the ecosystem to estimate service flows. Indices that are tied to observations at reference location(s), make the selection of those references even more critical.

Unanticipated Workshop Discussions

The topics and charge to the 5 groups at the beginning of the workshop were complex. The Organizing Committee anticipated an initial "calibration" period in which team-building dynamics were in play and the individual groups decided on how to proceed. Indeed, those activities during "calibration" did occur. However, not expected were the discussions that arose independently within and among each group. Those discussions revolved around two questions; "What is a HEA metric?" and "What is the relationship between the HEA metric and ecological service flows?" A significant workshop finding was that these two questions must always be addressed early in the NRDA process and certainly during HEA metric selection.

"What is a HEA metric?"

All of the groups brought up this question during their deliberations. Each group addressed the definition differently and at various levels of detail. What became apparent during the workshop was that participants had very divergent views on what constitutes a HEA metric. Some participants or groups conveyed a precise answer to the question while others provided a broader characterization. Some participants or groups even appeared to change their minds about what constitutes a HEA metric over the course of the workshop. The Organizing Committee observed that the level of cross-pollination and discussion among the participants and groups was excellent and robust.

In NOAA's HEA overview technical report (2006), a HEA metric is described as a value(s) or indicator(s) that can be defined for natural resource services that captures the level of services provided by a habitat, and captures any significant differences in the quantities and qualities of services provided by injured and replacement habitats. An invited speaker and several groups defined a HEA metric as a proxy for ecosystem services. The term "proxy" is also used in NOAA's HEA overview technical report (2006). Most groups sought to refine or more fully elaborate on the NOAA definition because defining the term explicitly as a group was critical to their deliberation of marsh metrics.

In helping answer the question of "What is a marsh metric?" several groups sought to identify the *characteristics* of an effective marsh metric. One group noted that an effective HEA metric should balance cost, precision/accuracy, and resources appropriately (Figure 2). This same group, however, noted that successful balancing was infrequent. One group conveyed that an effective HEA metric: (1) changes over time with restoration and recovery processes, (2) does not result in double counting, and (3) does not result in a compensation value of more than 100 percent during injury quantification. Additionally, the group mentioned that a HEA metric may not accurately reflect ecosystem services but may still be valuable for settlement during the NRDA process. Another idea emerging from the workshop was that an effective HEA metric reflects a common ecological service that is applicable during injury assessment, restoration planning/implementation, and any long-term monitoring (Figure 3). Another group described an effective HEA metric as an indicator of a thematic category of services, such as animal services, plant services, or sediment services.

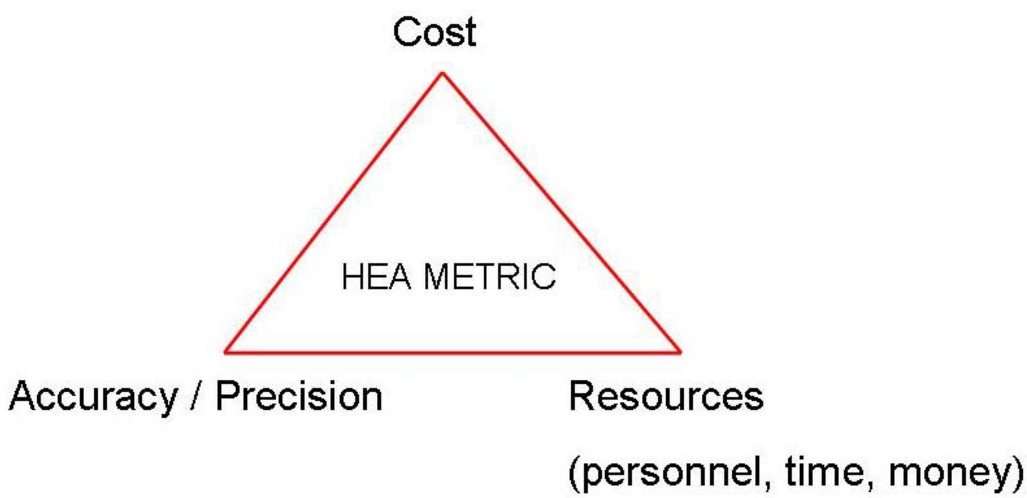

Figure 2. Conceptual diagram generated during the workshop showing that a HEA metric should balance cost, precision/accuracy, and resources. The conceptual diagram is adapted from a group at the workshop.

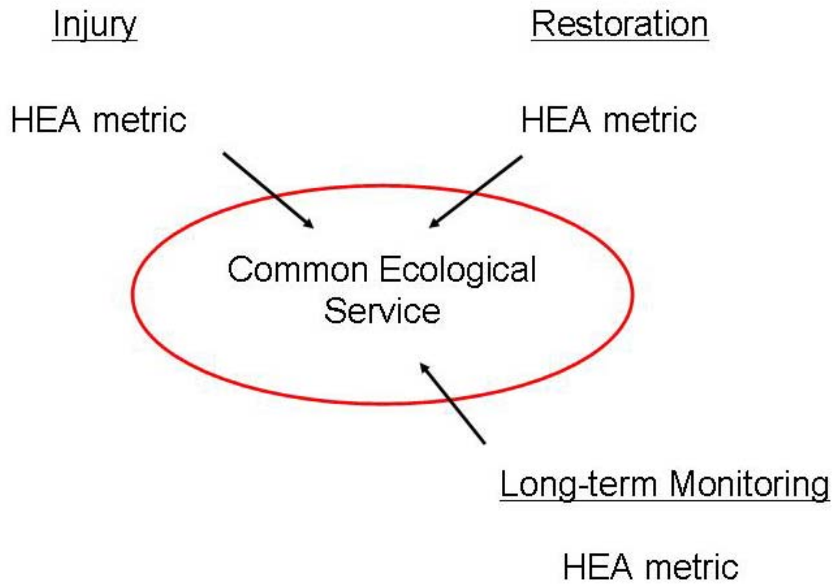

Figure 3. Conceptual diagram generated during the workshop showing that a good metric should reflect a common ecological service that is applicable to injury assessment, restoration planning and implementation, and associated long-term monitoring data. The conceptual diagram is adapted from a group at the workshop.

As noted above, NOAA's HEA overview technical report (2006) provides a definition for a HEA metric. This report was part of the pre-workshop reading material but obviously not all participants looked at it. In a post-workshop review, the Organizing Committee opined that presenting a precise definition of a HEA metric at the beginning of the workshop may have benefited the participants during their initial "calibration" period. The lack of a definition appeared to cause some level of confusion among the groups. However, this confusion may have paradoxically benefited the workshop by inducing the fruitful discussion. In a workshop populated by experts familiar with HEA, the strength and frequency of the definition discussion strongly suggests that this should be one of the first tasks of any stakeholder group undertaking a NRDA.

"What is the relationship between the HEA metric and ecological service flow(s)?"

In addition to defining a marsh metric, a second major unanticipated issue to emerge from the workshop was the need to describe the relationship between a HEA metric and ecological service flow(s). Several participants noted that the metric-service flow link is not adequately addressed by all practitioners at the beginning of the NRDA process, but should be explicitly addressed when selecting HEA metrics. Not adequately addressing this fundamental relationship at the start of a NRDA may result in confusion when outputs from HEA models are generated. Minimal discussion on the metric-service flow linkage may also result in "buyer's remorse" on the part of participant(s) near the end of the process because the chosen HEA input(s) did not accurately or precisely reflect expected injury or recovery of a habitat. Some participants advocated an approach where a single metric could serve as a proxy for service flows at multiple trophic levels rather than having multiple metrics measure service a single trophic level.

The decision to use structural versus functional marsh metrics was an important subtext in the HEA metric-service flow discussion. Over the course of the workshop, a variety of opinions were expressed about whether structural or functional HEA metrics are superior. Some participants argued that functional marsh metrics are preferable because they more closely represent ecological service flows. Quite a few participants challenged that assumption. One of the groups took the position that structural metrics may be superior to functional metrics because they are easier to measure and structural changes are more likely to be detected. As an example, when exposed to a high lethal dose, a significant number of organisms may die and these diminished numbers will be more readily apparent and easier to measure in structure marsh metrics such as abundance and density of species. At low doses, that same group explained, less sensitive species will “replace” the more sensitive species that have died. Again, replacement of sensitive species that died is more likely to be observed in structural metrics than a functional metrics, such as productivity. Some groups did not address the issue of structure and function in depth but indicated that reaching a common set of definitions for “structural” and “functional” is important before selecting marsh metrics for use in HEA.

By the end of the workshop, it was clear that developing a specific position on the HEA metric-service flow relationship that represented all the participants was not possible. Nevertheless, there was consensus by most, if not all participants that the metric-service flow relationship must be addressed early in the NRDA process, especially before selecting a marsh metric or suite of metrics for use in HEA. As with the metric definition question, the Organizing Committee felt that a formal acknowledgement of the metric-service flow link at the beginning of the workshop would have been beneficial. However, it was apparent from the vigor of the workshop discussions that any conceptual presentation offered by the Organizing Committee would have undergone re-discussion within each of the groups.

After more than a decade of using HEA during NRDA, there is still a continuum of ideas about what constitutes a suitable marsh metric for HEA, what makes an effective marsh metric, when to use certain marsh metrics, and whether one or many marsh metrics can truly serve as an indicator for ecosystem services. Despite the diversity of opinion on a wide range of these issues, many participants explicitly expressed the idea at the end of the workshop that the current process for marsh metric selection and the technical basis for using the top-rated metrics in NRDAs across the country are technically sound.

The Organizing Committee thanks the Coastal Response Research Center for hosting the workshop and all the invitees for their active participation.

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Appendix

Appendix A: Composition of Breakout Groups

Group A	Group B	Group C
Leader: Jerry Hall *Recorder: Nancy Kinner* OC: Tom Dillon Augspurger, Tom Curry, Mark Catena, John Grabowski, John Willis, Stephanie	Leader: Tony Penn *Recorder: Joe Cunningham* OC: Lisa DiPinto Baker, Mary Demond, John English, Eric MacDonald, Don Zelo, Ian	Leader: Pete Peterson *Recorder: Amy Merten* OC: Troy Baker Beckvar, Nancy Barnthouse, Lawrence Stahl, Ralph Sullivan, Laurie Young, Dale
Group D	**Group E**	
Leader: Andrew Davis *Recorder: Christine Voss* OC: Kate Clark Kern, John Macrander, Michael Pitts, Don Crowley, Christian Morrison, Ru	Leader: CJ Beegle-Krause *Recorder: Sarah Lilly/ Michele Jacobi* OC: Gary Shigenaka Brody, Neal Burdick, David Haddad, Bob Slocomb, John Wolotira, Robert	

Appendix B: List of Marsh Metrics

Note: This alphabetical list of metrics for saltmarsh was developed to stimulate thinking on the topic and should not be considered exhaustive. This list may not include new or emerging metrics on the horizon and may contain metrics that do not merit further evaluation.

1	Aboveground vegetative productivity or biomass
2	Belowground vegetative productivity or biomass
3	Adjacent submerged aquatic vegetation
4	Algae
5	Avian or terrestrial animal abundance, species richness, density, or presence/absence
6	Benthos abundance, species richness, density, or presence/absence (could be benthic macroinvertebrates or benthic infauna)
7	Chemical profile of water or porewater (e.g., dissolved oxygen or salinity)
8	Concentration or presence/absence of toxics
9	Current velocity quantification
10	Distance to open water or ratio of emergent vegetation and open water
11	Elevation and microtopography quantification
12	Epiphytic invertebrate abundance, species richness, density, or presence/absence
13	Fish and shellfish abundance, species richness, density, or presence/absence
14	Flood mitigation value/storm abatement
15	Frequency or width of trenasse or tidal creeks
16	Groundwater/recharge function
17	Habitat value for feeding or refuge
18	Human use for recreation or subsidence; aesthetics
19	Nutrient profile/availability
20	Organic matter content
21	Percent cover (live and dead)
22	Percent invasives
23	Percent survival of adults or seedling survival
24	Plant height
25	Rate of marsh expansion or contraction
26	Redox potential
27	Remote sensing (e.g., color of a pixel correlates to marsh health)
28	Sediment accretion rates
29	Sediment contamination
30	Sediment toxicity
31	Sediment grain size
32	Sediment transport quantification
33	Species composition
34	Stem density
35	Threatened and Endangered Species abundance, species richness, density, presence/absence
36	Tidal dynamics
37	Water depth
38	Water quality improvement or degradation
39	Water source identification/hydrologic exchange
40	Wave energy quantification