Habitat and Resource Equivalency Analysis: 30 Years of Lessons Learned and a Look to the Future

Wakefield, Jeffrey; Tomasi, Theodore; Morrow, Angeline; Pfeifer, Christopher; Byrd, Heath.

Cardno, Inc. 121 Continental Drive, Suite 308, Newark, Delaware, USA 19713.

ABSTRACT #2021-XXX: Natural Resource Damage Assessment (NRDA) under the Oil Pollution Act of 1990 (OPA) is a process used to determine the amount of compensation due to the public for natural resource injuries arising from oil spills. Two models, Resource Equivalency Analysis (REA) and Habitat Equivalency Analysis (HEA), are used in essentially all OPA NRDAs to compute compensatory restoration requirements. REA is applied when members of wildlife populations are injured: usually mortality or a loss of reproduction among a species of bird, turtle, marine mammal, or fish. HEA is used when habitats are injured: usually oiling of beaches, wetlands, or sediments.

The models are often implemented in a cooperative setting with input from both the Responsible Party and the Trustees. In this setting the models provide a structure for organizing negotiations and identifying the types of agreements that need to be reached before restoration can be identified and "right sized."

The models also have a technical basis in economic theory that is fully justified, but only in particular, limited circumstances. This technical basis is the only means of assuring the Trustees, RPs, and stakeholders that the NRDA process has identified an appropriate level of compensation. When the circumstances of a spill do not approximate those in which HEA and REA are defensible, creative solutions are needed to adjust the models to the circumstances of the case if they are to provide a convincing basis for scaling restoration and reaching resolution.

This paper identifies the circumstances under which REA and HEA are fully

defensible as well as 35 years of evolving adjustments designed to make them "work" when applied to real-world cases they do not quite fit. We also look to the future and how climate change may alter restoration scaling.

INTRODUCTION

The Oil Pollution Act of 1990 (OPA) allows designated natural resource trustee agencies ("Trustees"), acting on behalf of the public, to recover natural resource damages (NRDs) to compensate the public for ecological impacts that occur as the result of oil spills. By statute, funds collected from potentially responsible parties may only be used for natural resource restoration actions and to reimburse Trustees for "reasonable" assessment costs. The process of determining the appropriate amount of compensation is called Natural Resource Damage Assessment (NRDA).

When conducting a NRDA, the basic goal is to identify the type and scale of natural resource restoration that, when implemented, ensures the public is compensated for injuries to natural resources. NRD liability, measured in dollars, is then the cost of implementing the scaled restoration projects, plus Trustees' assessment costs.

Today, two assessment frameworks, Resource Equivalency Analysis (REA) and Habitat Equivalency Analysis (HEA) are nearly always applied during the NRDA process. These frameworks help NRDA practitioners identify ecological restoration projects that, when implemented, ensure that the public experience no net loss of ecological services as a result of the spill (NOAA 1997; NOAA 2000).

When used in a cooperative setting, the primary role of REA and HEA is often to provide a structure for organizing both information and discussions and identifying the agreements that need to be reached to identify and "right size" (scale) restoration. It has been suggested that, when used in this manner, REA and HEA need no strong technical underpinnings; if they help reach settlements, they have served a useful function.

That said, the models do have a technical basis in economics and that basis dictates the circumstances under which they are defensible in their basic form. It is because most real-world cases do not fully reflect these circumstances that "adjustments" are necessary to tailor the models to the case at hand. When adjustments are required, the technical underpinnings of REA and HEA provide the basis for assuring that the NRDA process has identified an appropriate level of damages.

This paper reviews the roles of REA and HEA in a typical damage assessment, identifies the circumstances under which REA and HEA are fully defensible, and discusses the adjustments often applied to make REA and HEA "work" when applied in real-world cases. We also look to the future and discuss how climate change may expand the need for creative adjustments if the models are to retain their usefulness in restoration scaling.

THE ROLE OF REA AND HEA IN A TYPICAL DAMAGE ASSESSMENT

This section is intended to provide a basic understanding of the role REA and HEA play in a real world NRDA setting as illustrated using a simplified, hypothetical oil spill.

On the evening of January 10, 2018, the dredge *Clay Thomas* released 1,500 barrels of Number 6 fuel oil into the Atlantic Ocean approximately 0.5 miles off the North Carolina coast. Strong winds blew the oil to shore stranding it above the normal high tide line. The oil came ashore unevenly along a five-mile stretch of barrier island beach that formed the seaward border of a wildlife refuge. Portions of the slick migrated through a small inlet resulting in the moderate oiling of approximately 9 acres of back-barrier marsh adjacent to the refuge.

During the response, water samples were collected in the shallow subtidal and intertidal zone. When tested, these samples contained no dissolved oil constituents. However, sunken oil surveys did identify oil agglomerations (tarballs) on nearshore subtidal sediments. The clean-up process began January 16 and continued through January 26.

Pooled oil was removed using oil sorbent material. Rakes and shovels were used to remove oil from the beach; oiled wrack was also removed. The refuge immediately inland of the oiled habitats was closed to waterfowl hunting from January 17 to January 27.

In the days following the spill, wildlife responders collected 25 dead common loons, 35 dead double crested cormorants, and 50 dead mallards during daily searches of the spill area. The area is wintering ground for shorebirds including the endangered piping plover; 1 dead and 1 live oiled piping plover were observed during response. Wildlife responders did not note any other concentrations of birds or wildlife (the absence of wildlife concentrations was noted as typical of the area in January); nor did they report observing other dead or live oiled birds or wildlife. In the spring following the spill, shorebird survival and productivity data were collected in a manner consistent with historical monitoring protocols. When reproductive success and survival among shorebirds in the affected area were compared to that of shorebirds on surrounding beaches, there was no discernable spill affect.

The only recreational service affected was related to the closure of the refuge and its effect on waterfowl hunters. The refuge reported that during the release-related closure 600 duck hunting trips were cancelled.

Based on the these facts, NRDA practitioners identified the following issues of concern: (1) shoreline oiling on sandy beach habitats, including the impact of response activities; (2) shoreline oiling of wetland habitats, including the impact of response activities; (3) oiling of sub-tidal sediments and potential exposure to organisms in sub-tidal sediments; (4) spill-related acute mortality among common loons, mallards, cormorants, and piping plovers ; and (5) the loss of waterfowl hunting opportunities due to the spill-related closure of the refuge. They further concluded that the scale of compensatory restoration for impacts to bird populations would be estimated via a series of species-specific REAs. Restoration for impacts to subtidal sediment, sandy beach, and wetland habitat would be estimated via a series of habitat-specific HEAs. Finally, economic methods would be used to assess the compensatory requirements associated with loss of recreational hunting opportunity.

The Role of REA

The basic assumption underlying REA is that all the services associated with wildlife populations are provided in direct proportion to population size. Therefore, if a spill results in the loss of individuals through mortality and/or reduced reproduction, the public can be compensated via restoration that increases the number of individuals in the population. This is typically accomplished by targeting limiting factors such as suitable nest sites, predation affecting adult survival, or food availability. For example, one could compensate the public for mortality among common loons by deploying nesting rafts that increase reproductive success of the loon pair that uses the raft. REA answers the questions, "How many nesting rafts need to be deployed and for how long?"[1]

The metric in REA is the Discounted Species Year (DSY). For example, one loon living for one year provides one loon-year of service. Loon-years occurring in the future are discounted[2] to reflect society's preference to have goods sooner rather than later all else being equal. The resulting unit is a Discounted Loon Year.

The REA process can be thought of as occurring in 3 steps. First, the baseline population level (the number of individuals that would have been in the population had the spill not occurred) is projected through time using some population projection model. Next, the same model is used to project the population level through time given the effects of the spill, the response, and the effects of a specified restoration project. Finally, an iterative

[1] This may mean implementing restoration away from the spill area; for example, loons killed in North Carolina may nest, and so be restored, in New England. For the Chalk Point spill in Maryland, injury to ruddy ducks was compensated by preservation of prairie pothole breeding habitat in North Dakota.

[2] Discounting is a process reflecting the idea that a service received in the future is worth less to the public than the same amount of that service received today. For example, if a constant 3 percent annual discount rate is assumed, a loon-year occurring in t years is worth $(1/(1.03)^t$ loon-years occurring today. A loon-year one year hence is equivalent to 0.97 loon-years occurring this year, and a loon-year occurring two years hence would be worth only 0.942 loon-years occurring this year, and so on.

process is used to identify the size of the restoration project that, when implemented, ensures that society experiences no net gain or loss of DSYs.

REA is often discussed in terms of debits and credits as illustrated in Figure 1. When the "with-spill-and-restoration" population projection is below baseline a debit, denominated in DSYs, accumulates. When the "with-spill-and-restoration" projection exceeds baseline a credit, also denominated in DSYs, accumulates. The species-specific injury is fully compensated (i.e., the restoration project is "scaled") when the credit is equal to the debit (Figure 1).

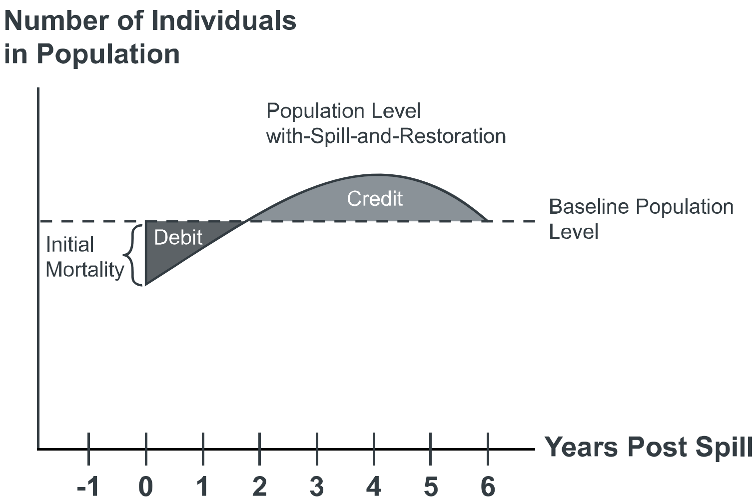

Figure 1. Graphical representation of REA.

The spill-related data and results of the four species-specific REAs led the assessment practitioners for the *Clay Thomas* to reach the following conclusions.

1. If 12 loon nesting platforms were deployed in Maine from 2025 through 2055, loon productivity (fledglings produced per female) would increase above its baseline level resulting in no net loss of discounted common loon years.
2. While piping plovers are an endangered species, the spill did not materially change extinction risk or recovery probabilities. Thus, a standard REA method was applied and indicated that a one-acre dune creation project would decrease plover nest predation and the resulting increase in productivity would

compensate for adult mortality. The dune creation project provides services to more than just plovers, so excess services will be produced.

3. While the spill resulted in a short-term increase in mortality among cormorants, cormorants are an identified nuisance species in the area and within the technical construct of REA, compensation is not necessary.
4. There are two ways through which the mallard population was affected by the spill. Some mallards exposed to oil died; and the refuge closure resulted in fewer birds being harvested by hunters relative to baseline. Noting that (a) the 50 carcasses collected were thought to represent 100 to 250 total mortalities and (b) the refuge manager estimated that 600 to 900 fewer mallards were harvested due to the hunting closure, the spill resulted in a net increase in the mallard population. The loss of recreational hunting requires compensation, but mallard mortality from oiling does not.

The Role of HEA

The basic premise underlying HEA is that the suite of services provided by a given habitat can be expressed as a single composite service. If a spill results in a reduction in the composite service produced by a habitat, compensation can be achieved via a restoration project that increases the amount of the composite service provided at some other site.

HEA is typically discussed in terms of debits and credits flowing from two discrete sites. Debits accrue when the level of composite service provided by the injured site is below baseline[3]; credits accrue when the level of composite service provided by the restored site is above baseline. Compensation is achieved when the credit is equal to the debit (Figure 2).

3 When estimating injury, the baseline level of composite service is defined as the level that would have been produced absent the spill.

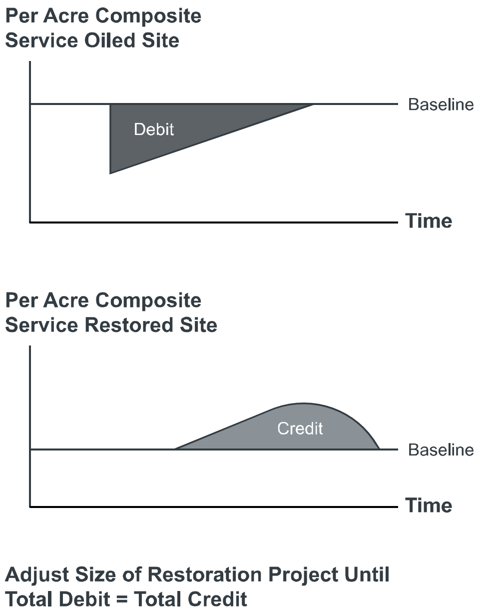

Figure 2. HEA illustrated as services flowing from two discrete sites.

The unit of analysis in HEA is a Service Acre Year (SAY) where the level of service provided by a base acre in one year is defined as one SAY. The injured and restored habitats are then judged relative to that base acre. If the base acre is a pristine site, a degraded acre may generate 50 percent services (or 0.5 SAYs), and a more degraded site may provide only 0.25 SAYs. SAYs are discounted; the resulting unit is a Discounted Service Acre Year (DSAY).

The facts of the *Clay Thomas* spill, in combination with the REA and HEA results, yielded the following conclusions.

1. The spill resulted in the loss of 35 subtidal sediment DSAYs. Because it is not practical to restore subtidal sediment in kind, NRDA practitioners opted to convert the subtidal sediment injury into an equivalent number of wetland DSAYs. Literature estimating the ecological value of sediment DSAYs relative to wetland DSAYs (Peterson et al. 2007), implies that 35 subtidal sediment DSAYs is equivalent to 7 wetland DSAYs. Additional literature indicates that wetland creation generates about 14 wetland DSAYs per acre.

A 0.5-acre wetland creation project would compensate for the spill-related impacts to subtidal sediment.

2. The spill resulted in the loss of 12 sand beach DSAYs. It was determined that, absent the piping plover restoration project, 0.75 acres of dune creation would offset the loss of sand beach habitat services. However, the one-acre plover restoration project would compensate for lost plovers, while also providing beach services. Moreover, beach habitats provide general services to shorebirds. For settlement purposes, it was agreed that 1 acre of dune creation would compensate for both piping plover injury and injury to sandy shoreline habitat.
3. The spill resulted in the loss of 21 wetland DSAYs. Consistent with the credit per acre estimated as part of the subtidal sediment HEA, credit for wetland creation is 14 DSAYs per acre. Thus, the creation of 1.5 acres of wetland would ensure no net loss of wetland services.

Identifying a Compensatory Restoration Package

The final restoration package was 12 loon nesting platforms, 1 acre of dune creation, and 2 acres of wetland creation. The package is based on REAs and HEAs with the following six assumptions that result in modifications to the standard assessment process. First, compensation for common loon mortality in North Carolina can be accomplished by restoration in New England. Second, when endangered species are affected by a release, if the effects of the spill and restoration do not materially change extinction risk or recovery probabilities, REA is an appropriate framework. Third, when REA is used to scale compensation for a species and compensation is accomplished via habitat restoration, the habitats will usually create surplus ecological services that may offset other injuries. Fourth, compensation for reductions in nuisance or invasive species is not necessary. Fifth, population projections in a REA should account for all the interrelated effects of the spill, estimating the net impact on the species. Sixth, out-of-kind compensation for a composite service reduction in one habitat type can be provided via a composite service gain in a different habitat type provided their services can be related using a ratio of relative service value.

Each of these assumptions and adjustments was adopted because the real-world NRD process does not conform precisely to the principles underpinning the basic REA and HEA frameworks. So, how can practitioners determine if the "modified process" has identified an appropriate level of damages? Such a determination requires an understanding of the theory that underlies REA and HEA.

WHEN ARE REA AND HEA DEFENSIBLE?

REA and HEA were originally developed as formal approximations of the economic model of compensation. As such, that model provides a standard against which the outcome of any REA or HEA-based assessments can be judged. This standard should also guide practitioners asked to apply REA and HEA in real world situations where they do not quite fit.

This section provides an overview of the economic theory of compensation which is the conceptual foundation of both REA and HEA. A more detailed treatment can be found in Wakefield, et al (2021). Referring to Figures 1 and 2, at each time step the vertical distance between the with-spill-and-restoration service level and the baseline service level is the amount of debit or credit in that time period. At issue is how these relate to compensating the public?

The OPA NRDA regulations define value as *"…the maximum amount of goods, services, or money an individual is willing to give up to obtain a specific good or service, or the minimum amount of goods, services, or money an individual is willing to accept to forego* *a specific good or service."* (15 CFR § 990.30) The first set of values define a willingness-to-pay (WTP) in money, goods, or services; the second define a willingness-to-accept (WTA) compensation in money, goods or services. The ideas in the definition accord exactly with those of economists. While WTA seems more relevant in NRDA, it is notoriously hard to measure, and for practical reasons, WTP is used as an approximation to WTA. WTP is focused on for this reason.

Figure 3 plots the amount of the service Q along the horizontal axis and WTP along the vertical axis. The curve WTP(Q) is WTP for a change from no services to services at the level Q. It is increasing, but steep near zero and flatter to the right. This means that an increment of services is worth more when services are scarce than when they are abundant. The full economic approach of value-to-value scaling is also depicted in Figure 3. WTP^I is the economic value of injuries and WTP^R is the value of restoration. In the full economic model with many time periods, the amounts WTP^I and/or WTP^R from Figure 3 would appear in Figures 1 and 2 for each time period, not SYs or SAYs. We will assume one time period, with the spill taking place and services recovering to baseline at the beginning of it and restoration at the end; the discount rate is zero. $Q^B - Q^S$ is DSAYs of injury, and $Q^{B+CR} - Q^B$ is DSAYs of service gain from restoration. Restoration is appropriately scaled when WTP^I equals WTP^R.

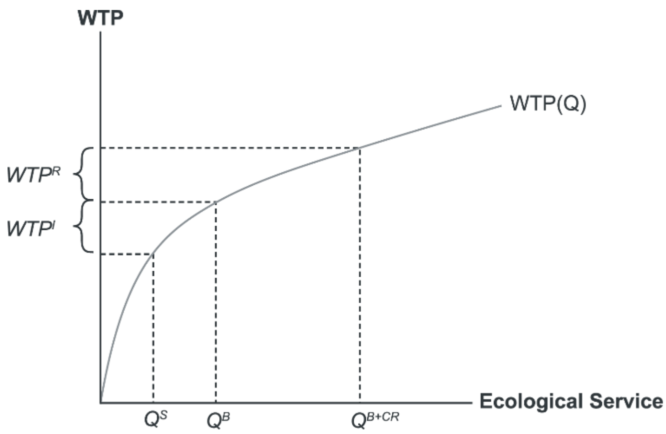

Figure 3. Economic Value-to-Value scaling of compensatory restoration.

In Figure 3, the marginal value of services (i.e., the slope of the WTP curve) is steep near Q^S and less steep near Q^{B+CR}. HEA and REA require that these are the same so they can cancel out of the scaling equation, which is then stated in terms of services alone. This constant marginal value assumption requires the value curve WTP (Q) to be a straight line, not curved. Thus, the HEA/REA value curve (which must be linear) can only approximate WTP at service levels near the baseline level. The resulting difference between REA/HEA and economic scaling are shown Figure 4. True economic values are read from the WTP curve; REA/HEA values are read from the approximation line. REA and HEA understate true debits and overstate true credits unless the amount of service change is small relative to the curvature in the WTP curve.

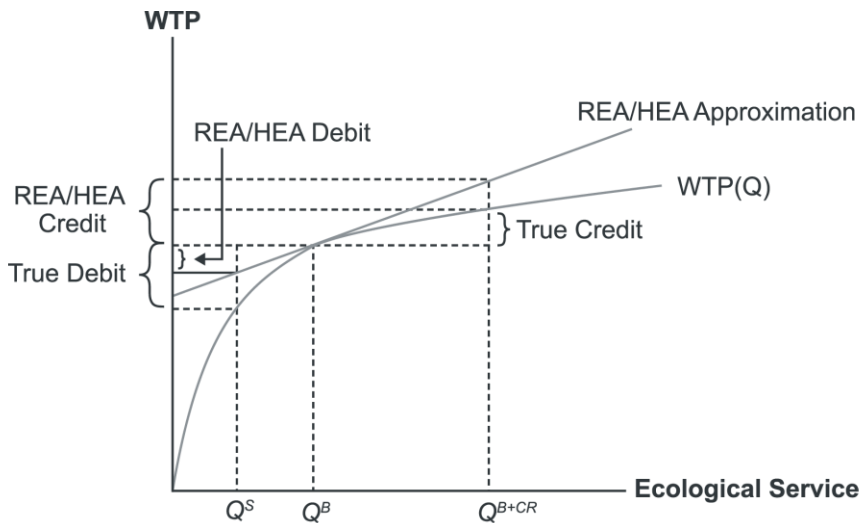

Figure 4. Economic scaling *versus* REA and HEA.

Figure 4 an also be used to illustrate the effect of a changing baseline service level over time. Suppose in early periods the baseline is far to the right; resource services are abundant when injury takes place. Both the WTP curve and the REA/HEA approximation will be flat (low incremental values). If restoration is initiated in a later period when the baseline service level is low, the WTP curve and REA/HEA approximation will be steeper reflecting higher incremental values. The approximation may be close in each time period, but the incremental values of injured and restored services are not the same in each time period, as REA/HEA requires. To avoid this, the regional baseline service level which drives resource values, needs to be approximately constant.

As detailed below, there are a number of formal assumptions that must hold if REA and HEA are to be consistent with the economic model.

The true economic benefit of the injury and restoration (i) are for goods and services that overall improve well-being (more is better) and (ii) take into account both ecosystem and behavioral adjustments by people.

(A1) Net Effects: *To be consistent with the economic model, REA and HEA should examine the net effects on service outcomes from all the various human and ecosystem adjustments to the spill and the restoration.*

In Figure 4, REA/HEA credits and debits increasingly diverge from the economic measures as the amounts of service change from baseline are larger, or the amount of curvature in the WTP curve increases. If $\mathrm{WTP}(Q)$ is linear, REA and HEA are exact approximations of the economic model in each period.

(A2) Small Effects: *In a single time period, HEA and REA will closely approximate the economic model when the injuries and restoration credits are small or when the WTP curve is nearly straight.*

If the services provided by restoration are of higher quality than those injured, the HEA and REA assumption of similar values is violated. An adjustment is need to bring these into accord; this is called a relative habitat value (RHV). This will reflect any source of value change.

(A3) Relative Habitat Values: *RHVs needed to adjust for service quality differences must reflect factors that affect economic values of services if a REA/HEA that embeds such an adjustment is to be accurate. These factors will generally include both bio-physical differences that alter the amount and quality of service provision (both on-site and* *landscape differences), and socio-economic factors that alter values across geographies.*

REA and HEA require that the incremental value of services is the same in every time period. If not, an adjustment needs to be made that reflects changing values as the baseline evolves. If Q is growing, the discount rate is higher; if Q is deteriorating, the rate is reduced (Wakefield et al. 2021). The amount of adjustment depends on the rate of change in services as well as the curvature of WTP(Q); more curvature means a greater adjustment and no curvature (linear WTP curve) means no adjustment, whatever the rate of growth.

(A4) Constant Regional Baseline: *The baseline level of services in the region of the spill must be approximately constant. If not, an adjustment to the discount rate is needed that accords with the economic model. A constant 3% discount rate, as is often used, will not generally be appropriate in this circumstance.*

Now we generalize the model to include multiple services. Value-to-value scaling is essentially unchanged, with individual preferences aggregating services into a composite index.

(A5) Aggregating Multiple Services: *With multiple services, services must be aggregated. In REA, the composite service is given by the amount of the resource. In HEA, either all services must move in fixed proportion to acres (the HEA is analytically a REA), or the composite service must be based on the individual's preferences, with weights that reflect relative incremental values of the services to be consistent with economics.*

If there are two (or more) people with differing preferences and only one service, the two people will disagree on the values of injury and restoration, but will agree on the amount of *primary* restoration. They will generally disagree on both the value of and amount of compensatory restoration, unless their preferences have a distinct shape and they have the same discount rate. This is not an issue for the economic approach, as long as money can be reallocated across people as additional compensatory "side payments" to get them to agree to a common restoration project. REA and HEA cannot accommodate this issue if the special preferences do not hold. With multiple services and multiple people, we essentially must assume people are the same. If people have different preferences, they will each build their own composite service and judge trade-offs between services differently. They will not come to agreement on scaling without actual monetary side payments, which does not occur.

(A6) Multiple people: *With multiple people and multiple services that do not change in fixed proportions across injury and restoration, people must be assumed to have identical preferences, including their discount rate.*

Finally, we address uncertainty. Suppose that the annual amounts of injury and restoration services gains are uncertain. Ad hoc adjustments are often made by making conservative assumptions about each uncertain scaling model parameter. This is not consistent with economics and often will lead to a significant over estimation of compensatory restoration requirements (Wakefield et al. 2021). NOAA (1999) recommends using expected values for uncertain parameters. This is a reasonable approximation if the WTP(Q) curve is either linear, or the REA/HEA approximation is close. If not, the economic adjustment is to use the certain amounts of debit or credit that are equivalent in value to the uncertain debits or credits. An adjustment to the discount rate can alternatively be used.

(A7) Uncertainty: *Uncertainty should be evaluated and addressed explicitly using economic methods. Generally, expected values can be used in REAs and HEAs that meet other assumptions. Otherwise, a certainty equivalent-approach or a risk-adjusted discount rate should be employed. Making a series of* ad hoc *conservative assumptions is not best practice.*

The conclusions in (A1) to (A7) are limitations placed on the realm of defensible application of REA and HEA. If these conditions are not closely approximated in the case at hand, adjustments must be made to REAs and HEAs, and these adjustments should reflect the logic of the economic model of compensation.

There is a trade-off between a more accurate model with adjustments requiring more analysis and a simple model that may be wrong but "close enough." Investing in more information to reduce uncertainty also raises a trade-off of accuracy and cost. Formal methods for making such decisions exist and should be considered as the basis for making the NRDA process more cost effective (Wakefield et al. 2021).

Revisiting the Clay Thomas REA and HEA in Light of Theory

Compensatory restoration as estimated via REA and HEA is reliable if the economic assumptions underlying the models hold in the circumstances being evaluated. Otherwise, it may be advisable to adjust the frameworks to address specific circumstances.

Returning to the *Clay Thomas* assessment, it is clear that the rationale behind the six embedded evaluations/adjustments was driven by the need to adapt the REA and HEA construct to the details of the spill.

1. REA and HEA assume that per-unit WTP to avoid injury is equal to the per-unit WTP to obtain restoration benefits (A2, A3). Compensating for loon services lost in North Carolina by creating loon services in New England appears likely to violate this requirement until one realizes that loons wintering in North Carolina likely spend their summers nesting in Maine and so loon services are, in large part, being provided at the location they were lost.
2. REA and HEA require the changes at issue to be small (A2). It is because of this requirement that, when evaluating piping plover compensation, the Clay Thomas assessors first determined whether the release was likely to change extinction or recovery probabilities. Had the spill materially changed the

probability of species extinction or recovery, one could not realistically characterize the changes as "small" and an augmented REA may have been required.

3. When REA is used to scale compensation for a species and compensation is accomplished via habitat creation, injures to the species are compensated and other services are created. Because the habitat restoration project create surplus ecological services, without adjustment, the public will be overcompensated (A3, A1). Thus, the surplus services should be used to offset, to the appropriate extent, other event related injuries. This is why the *Clay Thomas* assessors concluded one acre of dune creation compensated for both plover and sandy shoreline injuries.
4. Goods and services are defined so that "more is better" (A1). Thus, for nuisance cormorants, services would be inversely proportional to the number of cormorants present. The spill-related increase in the amount of cormorant-free habitat is preferred to baseline. Logically, no compensation is required; in fact, this effect of the spill should partially offset other spill-related service losses.
5. Preferences are defined over the amount of services provided. In the REA for mallards, services are proportional to the number of mallards and this should consider all spill-related factors that change the number mallards. These include both mortality increases from oil and decreases from hunting closures (A1). In the context of the *Clay Thomas*, no compensation is required. In fact, the spill-related increase in mallards could partially offset other injuries.
6. A fundamental tenant of the economic model, and so REA and HEA, is that individuals can rank different bundles of goods and services as better than,

worse than, or equal to a reference bundle. Thus, compensation for a reduction in the level of composite service provided by one habitat can be accomplished by increasing the level of composite service provided by a second habitat (or any other good) so long as the correct amount of composite service is provided by the second habitat. Thus, the *Clay Thomas* assessors were comfortable compensating subtidal sediment DSAYs with wetland DSAYs. That ratio at which these DSAYs ought to be exchanged (A3) is an ongoing topic of discussion; the concept of scaling "out-of-kind" restoration using RHVs is not.

LOOKING TO THE FUTURE

Wakefield et al. (2021) discusses several emerging issues related to the use of REA and HEA that indicate potential need for technical adjustments to current practice. Here, we focus on the effects of a changing climate on compensatory restoration scaling, a concern that embodies many of the emerging issues detailed in Wakefield et al. Rohr et al. (2013) address many of the science issues associated with climate change in NRDA, but some of the key restoration scaling issues are not fully developed. Here, we identify the following issues related to the use of REA and HEA in a world with a rapidly evolving climate.

Assumption A4 is that the baseline needs to be constant. If the resource base increases or decreases materially over the period when debits and credits accumulate, even small debits and credits occurring at different times provide different per-unit values. For example, the loss of 10 piping plovers when there are 1,400 breeding pairs (as there is today) is different than an increase of 10 piping plovers when there are only 25 breeding pairs left. In the latter case, the effects cannot even be considered small (A2). Adjustments to the discount rate could be used to address the first effect (A4) and associated uncertainties (A8), but cannot address the smallness issue (A2).

If a resource is injured in one place and restoration occurs in a different location, it is likely that service values will differ due to different surroundings (A3) or different people with different preferences (A6, A7). Climate change may prevent creation of services similar to those that were lost at locations near where losses occurred. Further, the best way to address the injuries in light of climate change may be a restoration action that is highly valued but out-of-kind. If so, NRDA will need to increase reliance on out-of-kind restoration and/or more carefully consider what it means to compensate by providing services in different geographies.

Climate change will increase both ecosystem fluctuation and uncertainty (A8). The formal treatment of uncertainty (pre NOAA 1999) will rise in importance. The use of risk-adjusted discount rates will likely come to the fore. When doing this, values for ecological services may be correlated to values for market goods. As in a financial portfolio, this covariance matters for valuation.

Finally, the service fluctuations caused by a rapidly evolving climate may alter the optimal timing of restoration. It may be best to time restoration to offset downturns in resource availability. Some fraction of restoration funds might be held and expend at places and times when negative shocks occur. Further, the uncertainty introduced by rapid climate change may increase the expected value of information creating incentives to (a) delay restoration and (b) improve adaptive management.

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