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Determining Ecological Equivalence in Service-to-Service Scaling of Salt Marsh Restoration

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ABSTRACT / The amount of ecological restoration required to mitigate or compensate for environmental injury or habitat loss is often based on the goal of achieving ecological equivalence. However, few tools are available for estimating the extent of restoration required to achieve habitat services equivalent to those that were lost. This paper describes habitat equivalency analysis (HEA), a habitat-based "service-to-service" approach for determining the amount of restoration needed to compensate for natural resource losses, and examines issues in its application in the case of salt marsh restoration. The scientific literature indicates that although structural attributes such as vegetation may recover within a few years, there is often a significant lag in the development of ecological processes such as nutrient cycling that are necessary for a fully functioning salt marsh. Moreover, natural variation can make recovery trajectories difficult to define and predict for many habitat services. HEA is an excellent tool for scaling restoration actions because it reflects this ecological variability and complexity. At the same time, practitioners must recognize that conclusions about the amount of restoration needed to provide ecological services equivalent to those that are lost will depend critically on the ecological data and assumptions that are used in the HEA calculation.

The amount of ecological restoration required to mitigate or compensate for environmental injury or habitat loss is often based on the goal of achieving ecological equivalence (Kentula and others 1992). Ecological equivalence refers to the capacity of a restored, created, or enhanced habitat to reproduce the ecological structures and functions provided by a resource before injury. Although this goal drives restoration actions, in practice ecological equivalence is difficult to define and achieve.

A regulatory application of the equivalence paradigm is in natural resource damage assessment (NRDA), in which natural resource trustees (certain federal, state, or tribal government agencies) seek restoration to compensate the public for losses of natural resources as a result of oil spills, hazardous substance releases, or certain physical injuries such as vessel groundings [Oil Pollution Control Act of 1990 (15 CFR Part 990)]. The objective of restoration actions undertaken as a part of the NRDA process is to fully recover the ecological services provided by a resource before injury (Chapman and others 1998, NOAA 1999b). Ecological services include the provision of food and habitat for fish and wildlife as well as ecological processes such as nutrient cycling. Determining the amount of restoration that will provide ecological services equivalent to those that were lost is a critical element of the overall damage assessment process.

KEY WORDS: Salt marsh; Ecological equivalence; Habitat equivalency analysis; Ecosystem services; Natural resource damage assessment

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As principal federal trustee for coastal and marine resources, the US National Oceanic and Atmospheric Administration (NOAA) is required to evaluate and restore, replace, rehabilitate, or acquire the equivalent of injured resources (Chapman and others 1998, NOAA 1999b). This includes both primary and compensatory restoration. Primary restoration is undertaken to return injured resources to the baseline level of services provided by the injured site before injury. Compensatory restoration compensates the public for lost services from the time of the injury to the return of baseline services. Compensatory restoration can involve either resource enhancement or creation.

NOAA has developed a habitat-based "service-to-service" approach for determining the amount of restoration needed to compensate the public for natural resource losses (Chapman and others 1998, NOAA 1999b). This approach, referred to as habitat equivalency analysis (HEA), scales the extent of restoration so that the total service gains provided at a compensation site will equal service losses at an injured site. HEA is used to evaluate restoration options using ecological rather than economic inputs. Because ecological services are difficult to value monetarily, HEA is used to directly link restoration activities to habitat injuries and service flows. The underlying assumption is that the public will accept a one-to-one trade-off between a unit of lost habitat services and a unit of restoration project services. There is not necessarily a one-to-one trade-off in terms of resources but in the services they provide.

In this article, we describe the HEA methodology with a focus on the interim loss portion of a damage assessment, illustrate the use of HEA in the context of salt marsh restoration, and examine the concept of equivalence as it applies to service-to-service scaling of restoration actions.

The HEA Procedure

Restoration scaling using HEA involves adjusting the size of a restoration action so that the value of habitat service gains equals the value of service losses resulting from a resource injury (Chapman and others 1998, NOAA 1999b). This is accomplished by reference to the baseline level of services at the injured site (i.e., the level of services provided by the injured site before injury). Baseline is determined by evaluation of a reference site that is similar but for the injury.

The HEA equation estimates service losses (the service debit) and service gains (the service credit) based on the extent and expected duration of a resource injury and the predicted trajectory of increases in ecological services through time due to restoration (NOAA 1999b). Key considerations are the timeline of the injury, the service reduction, the shape of the recovery curve, the percent services provided by the restored habitat, and the duration of restored services. Because losses and gains occur in different years into the future, a discount rate is applied to translate all service quantities into their worth in the present year.[1]

The HEA equation is:

$$\sum_{t=t_0}^{t_l} L_t \,(1 + i)^{(P - t)} = \sum_{s=s_0}^{s_1} R_s \,(1 + i)^{(P-s)}$$

where L_t is lost services at time t, R_s is replacement services at time s, t_0 is time when lost services are first suffered, t_l is time when lost services are last suffered, s_0 is time when replacement services are first provided, s_1 is time when replacement services are last provided, P is present time when the natural resource damage claim is presented, and i is periodic discount rate.

According to the HEA equation, the estimated service debit (the net present value of the injury per unit of resource) is the product of the number of habitat units injured and the percent of baseline (preinjury) services provided by restoration at the injured site per unit of injured habitat. The estimated service credit (the net present value of service gains expected from a unit of restoration at a compensation site) is the expected increase in services per unit of compensation habitat as a percent of baseline services per unit of injured habitat. The extent of compensatory restoration is scaled so that the estimated service credit matches the estimated debit. Figure 1 is a graphical representation of the service losses (debit) and service gains (credit) estimated using the HEA procedure.

Case Study: Use of HEA to Scale Salt Marsh Compensatory Restoration

Salt Marsh Services

The ecological services provided by a fully functioning salt marsh depend on the species present and the biological processes that help generate and maintain food and habitat for biota (such as primary production and nutrient cycling) (Table 1). Salt marshes provide habitat and forage for a wide range of resident and migrating fish, waterfowl, and wildlife (Chapman 1974, Teal 1986, Field and others 1991, Mitsch and Gosselink 1993, Kneib 1997). They are also important sites of nutrient cycling and transformation (Vernberg 1993) and are sinks for organic carbon and other nutrients as a result of sediment and peat accumulation (Nixon 1980, Craft and others 1999). These nutrient reservoirs are a source of nutrients for resident organisms and for export to the surrounding estuary (Valiela 1983, Deegan 1993).

Salt Marsh Restoration Scaling Metrics

Variables used to assess vegetation, such as biomass or stem density, are relatively easy to measure in salt marshes, and therefore such metrics are commonly used to assess recovery of the system as a whole following an oil spill or other injuries (Kusler and Kentula 1990, Kentula and others 1992, Thayer 1992). However, a growing literature suggests that many functional processes, such as nutrient cycling and food chain support, can take considerably longer to recover than structural components like vegetation (Table 2). As a result, structural measures alone may provide an incomplete picture of salt marsh recovery. In addition, recovery curves

[1]Use of a discount rate is based on the standard economic assumption that people place a greater value on having resources available in the present than on having availability delayed into the future, analogous to placing money in the bank at a given rate of interest (NOAA 1999a). Based on the economics literature and legal precedent, a discount rate of 3% is typically used.

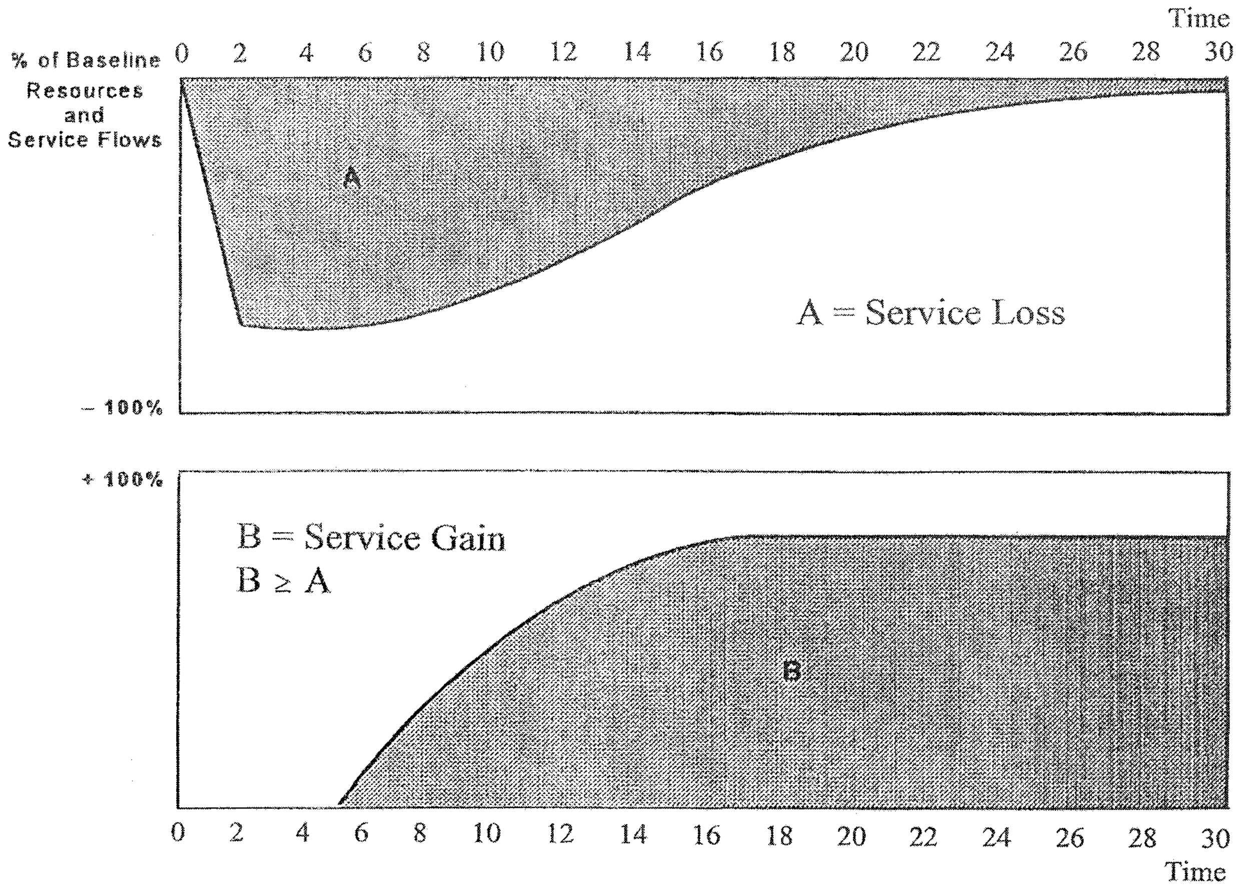

Figure 1. Graphical representation of changes in resource service levels through time at injured and restoration sites. The shaded portion **A** at the injured site indicates the service debit of the HEA calculation. The shaded portion **B** at the restoration site indicates the service credit.

can be highly variable even under natural conditions, making it difficult to predict the time for particular services to recover (Kentula and others 1992, Mitsch and Wilson 1996, Simenstad and Thom 1996, Zedler 1996, Weinstein and others 1997, Zedler and Callaway 1999). These considerations suggest that the level of restoration required to recover lost salt marsh services may vary substantially, depending on the data and assumptions used to implement restoration scaling.

HEA Example

Assume that in 2001 a salt marsh is injured by an oil spill. The resource trustees determine baseline (preinjury) services at a control site that is similar except for the injury and calculate the net present value of the service loss at the injured site as 500 acre-years. To compensate for lost services at the injured site, the trustees decide to transplant *Spartina alterniflora* at a nearby site. A HEA analysis is initiated to determine the size of the compensatory restoration project. Data on the ecological services provided by salt marshes are used to compare the required amount of restoration based on alternative HEA scaling metrics, as described in the following sections.

Primary production. Above-ground vegetation, as measured by percent cover, is the initial metric considered by the resource trustees for scaling the size of the compensatory restoration project using HEA. When basic site conditions are met, including elevation, slope, and tidal regime, vascular plant production increases rapidly on both restored and created sites (Niering and Warren 1980, Broome and others 1988, Broome 1990, Sinicorpe and others 1990, Niering 1997, Broome and Craft 1999). However, the time to recovery varies across sites and regions, depending on the rate of soil development and other processes that support vegetation growth. For example, studies of created marshes in North Carolina indicate that above-ground production is comparable to that of natural marshes within 1–3 years (Seneca and others 1976, 1985, Broome and oth-

Table 1. Ecological services of salt marshes and associated metrics

Marsh services	Examples of metrics
Primary production	Above-ground biomass, below-ground biomass, stem density
Habitat for biota	Canopy architecture of vegetation
Soil development and biogeochemical cycling	Soil and porewater nutrients, soil organic matter content, substrate particle size, soil moisture content, nitrogen fixation rates, denitrification rates
Food chain support	Density and biomass of vegetation, infauna, macrophyte detritus, and benthic algae
Fish and shellfish production	Density, species composition, diversity, biomass, population demographics

ers 1986, Craft and others 1988, 1991, 1999, Seneca and Broome 1992). However, even after 4 years, above-ground production of *S. foliosa* in southern California remained significantly lower than that of a nearby natural marsh (192 g/m^2 compared to 453 g/m^2), apparently due to the low soil organic matter and nitrogen content of the region's sandy substrate (Langis and others 1991, Gibson and others 1994).

For the HEA example considered here, assume that restoration activities will increase above-ground vegetation at the compensation site by 100% relative to the preinjury state at the injured site and that improvement will be realized 3 years after the start of restoration in 2002. The HEA calculation indicates that the net present value of lifetime gains per acre of compensatory restoration is 19.87 acre-years (Table 3). The service debit and service credit are equated as:

$$\text{loss of 500 acre-years} = \text{gain of 20 acre-years per acre} * R$$

where R is the number of acres of habitat needed for compensatory restoration. R is calculated as:

$$R = 500/20 = 25.0 \text{ acres}$$

as indicated in Table 4.

Habitat suitability. Although above-ground biomass and percent cover are often used as indicators of recovery, such metrics may fail to adequately reflect the quality of the habitat provided by vegetation. In fact, habitat characteristics such as stem height and weight generally decline over time as stem density increases (Figure 2) (Broome and others 1986, LaSalle and others 1991). For example, Zedler (1993) found that cordgrass canopy, defined by total stem length and number of tall stems, was a better indicator than vegetative biomass of the habitat value of constructed marshes for the endangered light-footed clapper rail (*Rallus longirostris levipes*).

If habitat suitability is used to scale restoration using HEA, and the trustees assume a 75% improvement in service flow over 10 years, then the estimated net present value of lifetime gains per acre of compensation is only 12.66 acre-years (Table 3), and 13 more acres will be required for compensatory restoration than if vegetative cover is used as the scaling metric (Table 4).

Soil development and biogeochemical cycling. Recovery of habitat quality is also a function of soil development and biogeochemical cycling. Because soils of restored and newly created marshes often have less organic matter than natural marshes, they typically contain fewer of the nutrients needed by marsh vegetation, particularly nitrogen (Cammen 1975, Lindau and Hossner 1981, Broome and others 1983, 1986, Valiela 1983, Craft and others 1988, 1991, 1999, Broome 1990, Langis and others 1991, LaSalle and others 1991, Minello and Zimmerman 1992, Sacco and others 1994). Sediment organic matter serves as a major nitrogen storage pool, and mature marshes with deeper organic matter layers recycle nitrogen more efficiently than young marshes (Thompson and others 1995, Currin and others 1996, Currin and Paerl 1998, Piehler and others 1998, Broome and Craft 1999). Studies show that C:N ratios, which indicate the availability of nitrogen to salt marsh plants, are not equivalent to those of natural marshes until the ratio drops below 20, which can take 15 years or more (Craft and others 1988, Craft 1999, and Broome and Craft 1999).

If soil nitrogen is used as the HEA scaling metric, and the trustees assume that there is only a 50% improvement in service flow over 25 years, then the net present value of lifetime gains per acre of compensation is only 6.13 acre-years per acre (Table 3) and more than three times as many acres will be required for compensatory restoration than if vegetative cover is used as the scaling metric (Table 4).

Food chain support. Benthic infauna (polychaetes and oligochaetes) and epibenthic fauna (crabs, snails, amphipods, and insects) are the primary food sources for higher order consumers in salt marshes, such as fish and shellfish. However, it is only once organic matter begins to accumulate in marsh soils that the marsh environment becomes suitable for invertebrate colonization (Sacco and others 1987, 1994, Moy and Levin 1991, Minello and others 1994, Peck and others 1994, Scatolini and Zedler 1996).

Table 2. Years to achieve maximum level of services for different services and metrics

Ecological service	Metric	Time (yr.)	Recovery (%)	Type of project	Location of marsh	Source
Primary production	Above-ground biomass	2–3	100	Created	NC	Craft and others (1999)
	Below-ground biomass	3	100	Restored	NC	Broome and others (1986)
	Stem density	5–6	100	Restored	NC	Broome and others (1986)
Soil development and biogeochemical cycling	Soil organic matter	24	29	Created	TX	Lindau and Hossner (1981)
	Soil nitrogen	24	50	Created	TX	Lindau and Hossner (1981)
	Soil carbon	5	8	Created	NC	Craft and others (1991)
	Macroorganic matter	15–30	100	Created	NC	Craft and others (1988)
	Dissolved organic C	5	34	Created	NC	Craft and others (1991)
	Dissolved organic N	5	60	Created	NC	Craft and others (1991)
	NH4-N	5	25	Created	NC	Craft and others (1991)
Invertebrate food supply	Infauna density and species richness	15–25	100	Created	NC	Craft and others (1999)
	Infauna community composition	1–17	100	Created	NC	Sacco and others (1994)
Secondary production	Shellfish density	3–15	93	Created	TX	Minello and Webb (1997)
	Fish density	3–15	41	Created	TX	Minello and Webb (1997)
	Shellfish density	5	20	Created	TX	Minello and Zimmerman (1992)
	Fish density	5	100	Created	TX	Minello and Zimmerman (1992)

Studies of created marshes in Texas, for example indicate that densities of invertebrate prey are directly related to the amount of macroorganic matter (dead and living roots and rhizomes) in *S. alterniflora* marsh soils (Minello and Zimmerman 1992). Because organic matter and soil nutrients are slow to recover, the production of infauna can remain lower in restored and constructed marshes for 15 or more years after vegetation establishment (Cammen 1976, 1979, Sacco and others 1987, 1994, Craft and others 1988, 1999, LaSalle and others 1991, Moy and Levin 1991, Levin and others 1996, Scatolini and Zedler 1996). As a result, the food supply for higher order consumers in restored marshes can differ significantly from that of natural marshes for many years after vegetation establishment (Simenstad and Thom 1996, Minello 1997).

If density of infauna is used as the HEA scaling metric, and the trustees assume 100% improvement in service flow over 15 years, then the net present value of lifetime gains per acre of compensation is 15.11 acre-years per acre (Table 3) and 8 more acres will be required for compensatory restoration than if vegetative cover is used as the scaling metric (Table 4).

Secondary productivity. Salt marshes provide nursery areas, foraging opportunities, and refuge from predation for resident and seasonal nekton species, including many commercially important fish and shellfish (Currin and others 1984, Zimmerman and Minello 1984, Shreffler and others 1990, Kneib 1991, 1997, Minello and Zimmerman 1992, Peterson and Turner 1994, Miller and Simenstad 1997, Minello and Webb 1997, Connolly 1999). Although fish and shellfish often colonize restored salt marshes relatively rapidly, density, biomass, and growth rates vary widely by species, study design, geographic location, sampling methods, and marsh age (Turner 1977, Meredith and Lotrich 1979, Allen 1982, Zimmerman and Minello 1984, LaSalle and others 1991, Rulifson 1991, Minello and Zimmerman 1992, Chamberlain and Barnhart 1993, LaSalle 1996, Burdick and others 1997, Minello 1997, Ambrose and Meffert 1999, Connolly 1999). As a result, estimates of secondary productivity, defined as produc-

Table 3. Sensitivity of HEA credit estimate to metric used in HEA calculation[a]

Variable in HEA model	Scenario 1: Primary production	Scenario 2: Habitat suitability	Scenario 3: Soil nitrogen	Scenario 4: Food chain support	Scenario 5: Secondary production
Projected years until compensatory restoration is completed	3	10	25	15	3
Preinjury services recovered at the end of compensatory restoration (%)	100	75	50	100	50
Present value of credit per acre of compensatory restoration during active restoration period	1.88	3.10	3.11	5.16	0.94
Present value of credit per acre of compensatory restoration (from end of primary restoration to 2100)	17.99	9.56	3.02	9.95	8.99
Total present value of credit per acre of compensatory restoration	19.87	12.66	6.13	15.11	9.93

[a]All estimates assume that the total present value of the injury is 500 acre-years, 0% services at the start of restoration, linear recovery paths, and a 3% discount rate.

Table 4. Sensitivity of size of compensatory restoration project to metric used in HEA calculation

Variable in HEA model	Scenario 1: Primary production	Scenario 2: Habitat suitability	Scenario 3: Soil nitrogen	Scenario 4: Food chain support	Scenario 5: Secondary production
Projected years until compensatory restoration is completed	3	10	25	15	3
Preinjury services recovered at the end of compensatory restoration (%)	100	75	50	100	50
Total present value of injury in acre-years (A)	500	500	500	500	500
Total present value of credit per acre of compensatory restoration (B)[a]	20	13	6	15	10
Estimated acres of compensatory restoration required (A/B)	25.0	38.5	83.4	33.3	50.0

[a]Per acre compensatory restoration credit values (from Table 3) were rounded to whole numbers for estimation of required compensatory restoration.

tion per unit of habitat per unit time, are difficult to compare across species and regions, even in natural marshes (Table 5). Comparable data on secondary productivity in created and enhanced marshes are unavailable, but information on density and biomass show variability comparable to that of secondary productivity in natural marshes.

Even within the same system, the rate and extent of colonization by nekton can vary widely by species. This appears to be related in part to patterns of habitat use. For example, in Texas, small fish such as darter goby (*Gobionellus boleosoma*) and pinfish (*Lagodon rhomboides*) use salt marshes primarily for protection and cover, and their recovery is more rapid than for species that depend on the development of food supplies, which can take several years (Minello and Zimmerman 1992). Similarly, in a constructed *S. alterniflora* marsh in Mississippi, increases in fish and shellfish density and bio-

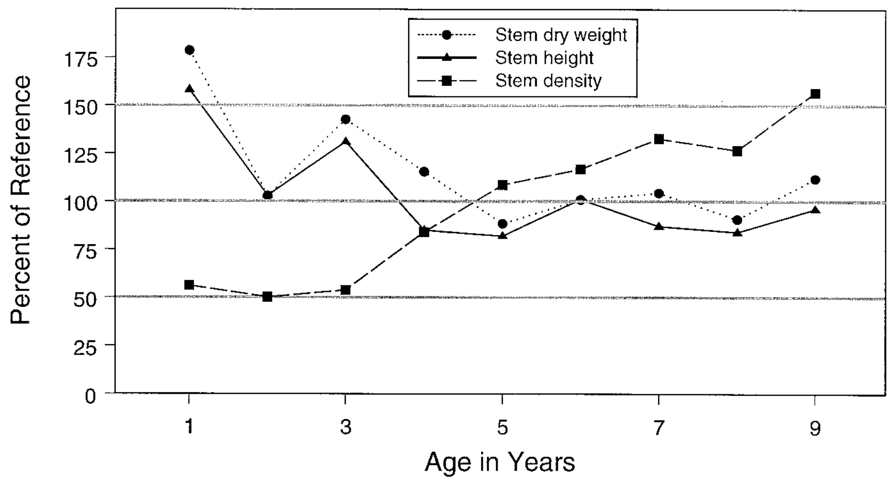

Figure 2. Changes over time in stem density, stem height, and stem dry weight in vegetation of restored marshes based on data in Broome and others (1986). For each metric, change is indicated as a percent of the reference value in natural marshes.

mass after 7 years varied widely by species and sampling period (LaSalle 1996). Densities of salt marsh transient species such as pinfish and gulf menhaden (*Brevoortia patronus*), which typically do not travel far into densely vegetated marshes, were up to 10 times higher in the constructed marsh, while densities of resident killifish (*Fundulus heteroclitus*) were less than 50% of that observed in a natural marsh. Transient species appeared to prefer the habitat provided by the lower elevation constructed marsh, which experienced more frequent and longer duration flooding.

In general, fish densities in restored marshes appear to be related more to tidal flooding regime and channel morphology than to marsh age (Chamberlain and Barnhart 1993, Minello 1997, Minello and Webb 1997, Zedler and others 1997, Ambrose and Meffert 1999). In a California study, fish utilization of salt marsh channels depended more on hydrology and elevation-related characteristics, including salinity, depth, sediment composition, and duration of tidal inundation, than on whether the salt marsh was natural or constructed (Zedler and others 1997). When formerly diked salt hay farms of the Delaware Estuary were restored by excavating channels to allow normal tidal inundation, which greatly improved fish access, fish and blue crab (*Callinectes sapidus*) production increased rapidly and actually exceeded that of reference marshes within a few years (PSEG 1999).

Even when colonization of created marshes by fish and shellfish is relatively rapid, populations may reach a plateau of recovery, with little or no improvement even several years after marsh establishment (Minello 1997, Minello and Webb 1997, T. Minello, National Marine Fisheries Service, Galveston, Texas, personal communication, 17 February 1999). Full recovery may take many more years, or it may be that salt marsh systems are so dynamic that trajectories will remain hard to define. Simenstad and Thom (1996) observed comparable growth and habitat use by juvenile salmon (*Oncorhynchus* spp.) in a created marsh over the short term, but concluded that the marsh was unlikely to sustain fish populations over the long term because of excess sediment accumulation. Low forage value may also be a factor. Chum salmon (*O. keta*) and chinook salmon (*O. tshawytscha*) in a created marsh in Tacoma, Washington, had emptier stomachs than the same species in reference marshes, possibly indicating reduced prey availability (Shreffler and others 1992).

Other studies have found reduced sizes of nekton in restored marshes. Minello and Zimmerman (1992) observed reduced size of grass shrimp in 2- to 5-year-old transplanted *S. alterniflora* marshes relative to natural marshes, reflecting the lower food value of the created marshes. In a related study, Minello and Webb (1997) found that although density of the grass shrimp in created marshes was similar to that found in a natural marsh, mean size was significantly lower.

If fish density is used as the HEA scaling metric, and the trustees assume only a 50% improvement in service flow over 3 years, then the net present value of lifetime gains per acre of compensation is 9.93 acre-years per acre (Table 3), and twice as many acres will be required for compensatory restoration than if vegetative cover is used as the scaling metric (Table 4).

Conclusions

As restoration scaling methods continue to evolve, it is critical to consider the meaning of "equivalence" and "recovery," given the variation inherent in ecological data and in the rates of development of different ecosystem components. Our analysis makes clear that con-

Table 5. Estimates of annual productivity of fish and shrimp in natural salt marshes

Species or assemblage (common name)	Location	Production ($g\ DW/m^2/yr$)	Source
Leiostomus xanthurus (spot)	Tidal marsh creeks	0.3–7.5	Currin and others (1984)
Palaemonetes pugio (grass shrimp)	Tidal marsh creek	9	Kneib (1997)
Fundulus heteroclitus (killifish; mummichog)	Tidal marsh creek	10.2	Meredith and Lotrich (1977)
Fundulus heteroclitus (killifish; mummichog)	New England tidal marsh creek	16	Valiela and others (1977)
Palaemonetes pugio (grass shrimp)	Embayment surrounded by marsh	16	Kneib (1997)
Micropogan undulatus (Atlantic croaker)	Louisiana marsh	21.8	Day and others (1973)
Brevoortia patronus (Gulf menhaden)	Louisiana estuary	38[a]	Deegan (1993)
Penaeid shrimp (heads-off)	Gulf Coast region, including FL, AL, MS, LA, and TX coasts	3.4b[b]	Turner (1977)
Fish, dominated by *Atherinops affinis* (topsmelt silverside)	Littoral zone of CA marsh	9.4	Allen (1982)
Total fish	Louisiana salt marsh	22.1	Day and others (1973)
	South Atlantic region, including NC, SC, GA, and east FL coasts	32.0[c]	de la Cruz (1981)
	Gulf Coast region, including FL, AL, MS, LA, and TX coasts	48.5[c]	de la Cruz (1981)

[a]Value represents average export of biomass per year from the estuary to the Gulf of Mexico by menhaden, a transient species.

[b]Value represents average regional fisheries yield (wet weight) per unit area of supporting intertidal marsh.

[c]Value represents total regional fisheries yield (wet weight) in 1976 per unit area of supporting intertidal marsh.

clusions about equivalency will depend critically on the data and assumptions used to implement scaling methods. In salt marsh restoration, structural measures such as vegetative ones may indicate full recovery within a relatively short time, but functional measures often reveal a significant lag in the recovery of ecological processes such as nutrient cycling that are necessary for a fully functioning marsh. As a result, 100% recovery of some ecological services may represent only partial recovery of the system as a whole.

Moreover, short-term recovery may not imply long-term sustainability (Zedler 1993, 1996, Simenstad and Thom 1996). Even when species densities in created marshes equal or exceed those of natural marshes, altered trophic relationships and ongoing changes in physical conditions may affect the forage value of restored and created marshes and the long-term sustainability of resident species. Although many restoration practitioners prefer to use population-based metrics based on the view that populations are of greater ecological relevance than individuals, the lack of long-term data increases the uncertainties associated with population measures. Thus, in some cases the growth or condition of individuals may prove to be a better proxy measure for salt marsh recovery, at least over the short term (e.g., Miller and Simenstad 1997).

Irrespective of the metric selected, injury settlements should include monitoring provisions and the flexibility to adjust restoration actions as needed based on monitoring results (Wickham and others 1993). There is a need for consistency in the methods used to measure, monitor, and report values for the parameters used to evaluate restoration activities. In addition, because restoration success depends in part on whether a site retains some of the attributes needed to support ecosystem processes, there is a need to evaluate the functional characteristics of restoration sites. The hydrogeomorphic (HGM) approach develops indices of wetland function based on geomorphic setting, water source, and hydrodynamics (Smith and others 1995). Because of the focus on functional attributes, metrics developed for salt marshes using the HGM approach may prove useful for HEA scaling.

The sensitivity of HEA to the data and assumptions used to calculate the required extent of compensatory restoration does not invalidate its use. Rather, HEA is a valuable tool precisely because it reflects, rather than obscures, ecosystem variability and complexity. At the same time, the sensitivity of HEA to data inputs points to the importance of testing assumptions and improving the data available to quantify habitat services, relationships among structural metrics and ecological functions, and recovery trajectories. As research continues to increase data availability, restoration success is best evaluated using a flexible approach that compares results using multiple metrics and assesses equivalence based on the "weight of evidence." Such an approach will help ensure that restoration actions meet the ultimate goal of recovery: an ecosystem's full functional capacity.

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