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Integrating biology and economics in seagrass restoration: How much is enough and why?

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Abstract

Although success criteria for seagrass restoration have been in place for some time, there has been little consistency regarding how much habitat should be restored for every unit area lost (the replacement ratio). Extant success criteria focus on persistence, area, and habitat quality (shoot density). These metrics, while conservative, remain largely accepted for the seagrass ecosystem. Computation of the replacement ratio using economic tools has recently been integrated with seagrass restoration and is based on the intrinsic recovery rate of the injured seagrass beds themselves as compared with the efficacy of the restoration itself. In this application, field surveys of injured seagrass beds in the Florida Keys National Marine Sanctuary (FKNMS) were conducted over several years and provide the basis for computing the intrinsic recovery rate and thus, the replacement ratio. This computation is performed using the Habitat Equivalency Analysis (HEA) and determines the lost on-site services pertaining to the ecological function of an area as the result of an injury and sets this against the difference between intrinsic recovery and recovery afforded by restoration. Joining empirical field data with economic theory has produced a reasonable and typically conservative means of determining the level of restoration and this has been fully supported in Federal Court rulings. Having clearly defined project goals allows application of the success criteria in a predictable, consistent, reasonable, and fair manner. Published by Elsevier Science B.V.

Keywords: Seagrass; Restoration; Success criteria; Goals; Discounting; Lost ecological services; Recovery; Habitat equivalency; Population growth

1. Introduction

Guidelines for site selection, monitoring, and success criteria for seagrass beds have changed little in the past decade (Fonseca, 1989, 1992, 1994). These criteria focus on achieving an initial level of planting unit survival that could generate

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the targeted acreage of seagrass in a prescribed period of time. Shoot density has also been combined with survival and acreage as an indication of the (asexual) reproductive capacity of the plantings. However, physical setting, which influences seagrass landscape pattern (Fonseca and Bell, 1998), could also alter the rate of bottom coverage. Thus, basic ecological information in the form of intrinsic population growth and coverage rates, net population growth rate, and environmental setting have been combined to provide guidance and set expectations of resource managers faced with restoring injured seagrass ecosystems. However, the manner in which these data are applied in order to determine the quantity of habitat restoration that must be performed, has often been inconsistent. In this paper we explore how basic ecological data on habitat recovery, restoration effectiveness, and society's value system may be linked to provide fair and consistent computations on the extent of habitat restoration that must be performed to compensate for anthropogenic injuries.

The purpose of habitat restoration (the term 'mitigation' is sometimes used) is to 'compensate for environmental damage or loss of habitat through replacement of functions, values, and/or acreage' (Race and Fonseca, 1996). Federal wetland regulations require the traditional sequence of injury avoidance, minimization, and, as a last choice, compensation through active restoration. Compensatory restoration has been seen as a means of ameliorating wetland losses. In many cases, some quantity of wetland must be generated at some time after the initial injury has occurred. The amount of wetland to be generated compared with the amount of wetland injured is generally referred to as the 'replacement ratio' and is usually (but not always) greater than unity, inferring that the replacement habitat is equal to or larger than the injured area. That ratio has varied widely among habitat types, regions, and governmental agencies, from less than unity to as much as 5 U of restored habitat for every 1 U lost (pers. obs.). The actual value of the replacement ratio has, to all appearances, emerged from value judgments about the criticality of the injured wetland itself, e.g. was it endangered species habitat? is it difficult to replace? and how long will it take to reach pre-injury functions? High replacement ratios may also be driven by the generally discouraging track record of mitigation projects (Nicholas, 1992; Roberts, 1993). Moreover, it has been suggested that projects with low replacement ratios must be then followed by other projects with higher ratios of replacement in order to maintain a regional baseline of wetland acreage (Race and Fonseca, 1996).

The replacement ratio should be set to recoup all lost ecosystem services — in particular, the loss of resource functions and products that occur between the time of habitat injury and the time to full recovery. Because the concepts of success and functional equivalency are so closely tied, planning for successful restoration and/or mitigation requires early incorporation of interim loss considerations. However, as mentioned earlier, the manner in which interim ecosystem losses computed has been inconsistent. Often, the ratio appears to be inversely proportional to the degree of public interest in the project causing the habitat injury.

Computation of lost resource services requires three assessments, (1) acreage of habitat lost; (2) the length of time needed for the functions associated with that area (and lost to the ecosystem at large during the period of the injury) to recover to their pre-impact levels; and (3) the shape of that recovery function. Using seagrass ecosystems as an example, if 1 ha of seagrass were destroyed today and replanted tomorrow and, for argument's sake, reached standards of equivalency in 2 years, the interim loss of ecological services over this 2-year period would be relatively low. However, if the restoration of this site were not undertaken immediately and if the site required 7 years to reach its pre-impact state, the level of compensation due the public for the interim losses from this same 1-acre injury would be substantially higher, highlighting the weakness of fixed compensation ratios.

Actual projects rarely enjoy tight temporal coupling either between the injury and on-site repair work, or between the injury and the additional restoration (beyond that necessary to return the injured site to baseline) required to compensate for the ecological services lost from the time of the injury until full recovery. Among other issues, it is very difficult to consistently locate and successfully create new seagrass habitat that meets ecologically responsible site selection criteria (which precludes simply substituting naturally unvegetated bottom for vegetated bottom). Finding large acreage of suitable substrate for restoration in close proximity to the impacted area is rare, and often results in restoration at sites physically removed from the impact area. Thus, any functions affected by spatial elements of ecosystem linkages (i.e. geographic setting) are lost. Second, the lost production was removed from a specific point in time. Therefore, in some instances it cannot be returned in a way to avoid disruption of ecosystem functions, such as the loss of last year's spawn of herring that might occur as a result of injury to a seagrass bed. Moreover, if there were a longer period of time between the injury and full recovery from the injury, then one could argue that plantings conducted longer after an impact have less value than ones conducted sooner. This realization is the basis for the new approaches by National Oceanic and Atmospheric Administration (NOAA) to standardize the problem of computing interim loss services objectively and quantitatively, which then provide a basis for setting replacement ratios and arriving at a quantity of persistent acreage of given quality, that has been defined as an appropriate metric of success (Fonseca, 1989, 1992, 1994; Fonseca et al., 1998).

Determination of interim loss and its implementation into the restoration process is tightly integrated with the establishment of a restoration plan. While such a plan must identify the mechanics of the physical restoration itself, the plan must also have a clear definition of injury, site selection, monitoring protocols, and success. As mentioned earlier, those guidelines had been established (Fonseca, 1989, 1992, 1994), but have not yet been quantitatively coupled with the issue of interim loss to determine replacement ratios.

Recently, NOAA developed and implemented a protocol termed 'Habitat Equivalency Analysis' (HEA) that utilizes basic biological data to quantify these interim lost resource services (NOAA, 1997a). While sharing many of the same principles as other methods for incorporating interim losses into replacement ratio calculations for wetlands (Unsworth and Bishop, 1994; King et al., 1993), HEA focuses on the selection of a specific resource-based metric(s) as a proxy for the affected services (e.g. seagrass short-shoot density in the example discussed below), rather than basing its calculations on a broad aggregation of services impacted. This approach has the advantage of making HEA applicable not only to a wide range of different habitats, but to injuries of individual species as well (see Chapman et al., 1998, for a discussion of HEA applied to the calculation of compensation for historic salmon losses). Additionally, the selection of a resource-based metric allows for differences in the quality of services provided by the injured versus replacement resources to be captured and incorporated with the replacement ratio (NOAA, 1997b). Without specification of a quantifiable resource metric, analysis of the recovery of the resource following injury and/or the success of the restoration project may be difficult to evaluate precisely. For example, in the wetlands context, alternative metric specifications may lead to significantly different maturity horizons (Broome et al., 1986) as well as the level of functional equivalence ultimately achieved by the restoration project (Zedler and Langis, 1991). In the remainder of this paper, we report on how this linkage was established by reviewing the theoretical and biological bases of a restoration plan that was developed in response to the destruction of a subtropical climax seagrass bed (*Thalassia testudinum*), how HEA was utilized in the plan, and how this procedure influenced project goals and success criteria.

2. Case study: an example of how the HEA may be applied

An example of applying HEA to habitat restoration occurred in a recent Federal court case (United States of America vs. Melvin A. Fisher et al., 1997) to provide compensation for the loss of 1.63 acres of seagrasses (turtlegrass, *T. testudinum*) within the Florida Keys National Marine Sanctuary (FKNMS). Extremely energetic hydrodynamic conditions at the injury site together with intense grazing of the seagrass by nocturnal animals prevented successful establishment of plantings. Therefore, off-site restoration was chosen in the form of in-kind (same species) repair of *T. testudinum* beds damaged by boat propeller scars (prop scars). This approach focused initially on planting a native pioneering seagrass species, *Halodule wrightii*, to facilitate the eventual recovery of the slow-growing *T. testudinum*. This sequence, termed 'compressed succession' (M. Moffler, pers. commun.), promotes more suitable conditions for *T. testudinum* to naturally encroach upon the prop scar while stabilizing the site and preventing additional erosion. Project success was to be quantified by four parameters, (1) an average of minimum one horizontal *H. wrightii* rhizome apical per planting unit must be installed at planting; (2) survival of planting units would be not less than 75% at the end of year 1; (3) seagrass shoot density would not be statistically different from that of nearby natural beds; and (4) the target acreage of bottom coverage would be achieved within a 3-year monitoring period. Additionally, if monitoring indicated that, performance standards were not being met or were not been projected to meet, remedial plantings of those affected areas were designed into the plan. However, all remedial plantings reset the monitoring clock for that portion of the project. The ultimate success criterion was unassisted persistence of target bottom coverage by the seagrass plantings for 3 years, with photo documentation providing a common basis of assessment, perception, and historical reference.

Key factors in NOAA's development of a restoration plan have been the issues of pre-project planning, particularly regarding site suitability. Here, sites were reviewed for the suitable use of the following criteria, (1) they were adjacent to natural seagrass beds at similar depths; (2) they were anthropogenically disturbed; (3) they existed in areas that were not subject to chronic storm disruption; (4) they were not undergoing rapid and extensive natural recolonization by seagrasses; (5) seagrass restoration had been successful at similar sites; (6) there was sufficient acreage to conduct the project; and (7) similar quality of habitat would be restored as was lost. The restoration of seagrass prop scars created by vessel impacts represented NOAA's preferred approach to seagrass restoration off-site. In order to select a planting site that could accommodate the project's size, the amount of restored acreage was computed using the HEA, which is reviewed next.

3. Description of the compensatory restoration[1] scaling approach

Accurate determination of the appropriate scale of compensatory restoration projects is necessary to ensure that the public and the environment are adequately compensated for the interim service losses resulting from the injuries to natural resources. For injuries to seagrass resources, NOAA has employed HEA as the primary methodology for scaling compensatory restoration projects. The principal concept underlying HEA is that the public and the environment can be made whole for injuries to natural resources through the implementation of restoration projects that provide resources and services of the same type, quality and comparable value. HEA has been applied to cases centered on seagrass injuries because those incidents typically meet the three criteria defined by NOAA and upheld by the US District Court (United States of America vs. Melvin A. Fisher et al., 1997) for use of HEA, (1) the primary category of lost on-site services pertains to the biological function of an area (as opposed to direct human uses, such as recreational services); (2) feasible restoration projects are available that provide services of the same type and quality and are comparable in value to those that were lost; and (3) sufficient data on the required HEA input parameters exist and are cost effective to collect. Note that if these criteria are not met for a particular incident, other valid, reliable approaches and methodologies are available for

[1] 'Compensatory restoration' refers to any action taken to compensate for interim losses of natural resources and services that occur from the point of the injury until recovery of those resources/services to baseline. Conversely, 'primary restoration' refers to actions that return the injured natural resources and services to baseline.

scaling the chosen compensatory restoration projects (NOAA, 1997b).

At its most basic level, HEA determines the appropriate scale of a compensatory restoration project by adjusting the project scale such that the present value of the compensatory project is equal to the present value of interim losses due to the injury[2]. This 'balancing' of gains and losses is accomplished through a four-step process (NOAA, 1997a). First (step 1), the extent, severity, duration of the injury (from the time of the injury until the resource reaches its point of maximum recovery), and functional form of the recovery curve must be determined, in order to calculate the total interim resource service losses.

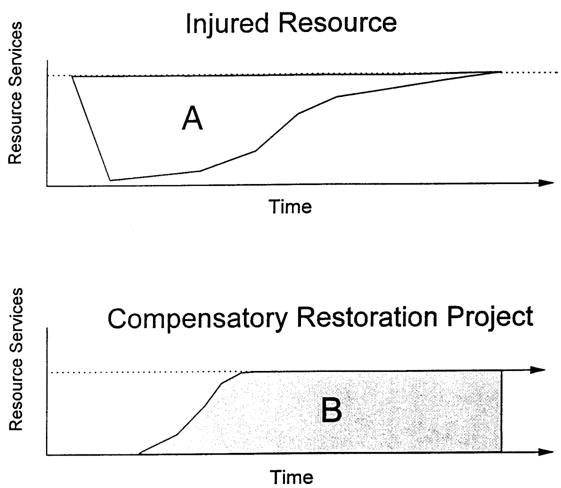

Fig. 1. Depiction of how habitat equivalency analysis accounts for those resource services lost by an injury (A) and those returned in the compensatory restoration project (B). The curves in this figure represent undiscounted, rather than the discounted, service flows (cumulative provision of services over time) in order to depict more clearly the biological processes of recovery and maturity.

[2] In some instances, it may be beneficial to all parties involved to implement a project where the total discounted gains from the compensatory project exceed the total discounted losses. This situation occurs when the scale of the preferred project can only be adjusted according to a binary or step-wise function rather than a continuous function, or when the resulting amount of natural resources/services generated by a restoration action cannot be tightly controlled following implementation of that action (e.g. freshwater diversion projects intended to create wetland acreage.

Next (step 2), the resource services provided by the compensatory project, over the full life of the project, must be estimated to quantify the benefits attributable to the restoration. This step is analogous to the previous one and requires estimation of both the time required for the compensatory restoration project to reach its maximum level of service provision and the functional form of the maturity curve. After these resource service losses and gains have been quantified, the scale of the compensatory project is adjusted until the projected future resource service gains are equal to the interim losses associated with the injury (step 3). This process is depicted graphically in Fig. 1, where the scale of the compensatory restoration project is adjusted until the area under the maturity curve (the total resource service gains, represented by area B) is equal to the interim lost resource services (represented by area A). Because, these services are occurring at different points of time, they must be translated into comparable present value terms through the use of a discount rate. Discounting is a standard economic procedure that adjusts for the public's preferences for having resources available in the present period relative to a specified time in the future. Because of discounting, plantings that occur longer after an impact are worth less in present value terms than plantings conducted shortly after an impact, and therefore more planting must be done as time elapses. Finally (step 4), appropriate performance standards associated with the compensatory restoration must be developed to ensure that the project provides the anticipated level of services. Well-defined and measurable standards are essential to the success of the project regardless of whether the restoration will be implemented by the parties responsible for the original resource injury or whether the trustees will receive monetary damages to implement the projects themselves.

As part of the scaling process, it is not feasible to measure and quantify each of the individual resource services provided by seagrass habitats, such as fish and benthic production, sediment stabilization, nutrient cycling, water quality enhancement, and primary productivity. Thus, essential to the successful application of HEA is the development of a resource metric that is closely correlated with the services provided by both the injured and compensatory habitats. An appropriate metric captures relevant differences in the quantities and qualities of services provided by the injured and compensatory habitats. In past NOAA seagrass cases, short-shoot density has been used as the resource metric for quantifying the resource services provided by the injured and compensatory habitats. Short-shoot density is relatively easy to measure nondestructively and represents an important metric of plant coverage that is the basis for the functional role of seagrass habitat in providing food, shelter, sediment stabilization, and nutrient cycling services. Increases and/or decreases in shoot density generally indicate the growth status of the entire population and not just individuals within the population. It is, however, a conservative metric because it does not account for the ecological services provided by the below-ground production and function of roots and rhizomes, a portion of the *T. testudinum* plant community that takes many more years to develop than shoot density so as to provide nutrient cycling and sediment stabilization equivalent to that of natural beds. Moreover, in both the compensatory project selection process and in the development of an appropriate resource metric, it is important to consider the landscape context as well as the biophysical characteristics of the site (e.g. access by fauna to the site, material flows to and from adjacent communities, erosion control).

4. Development of model input

In order to conduct the HEA computation, an empirical assessment of natural seagrass recovery rates was required. If natural recolonization was very high, then planting would have little strategic advantage in accelerating recovery and the difference in the recovered discounted services as the result of planting versus natural recovery would be low, indicating that the project would not substantively accelerate the return of ecosystem services. Determination of these recovery rates is therefore critical for implementing the HEA. Estimates for relative recovery rates of different species of tropical and temperate seagrasses are generally known and several studies reported the critical abundance and the growth parameters needed to begin formulation of the recovery model (den Hartog, 1971; Patriquin, 1973; Zieman, 1982; Williams, 1987; Fonseca et al., 1987; Williams, 1990; Duarte, 1991; Tomasko et al., 1991; Gallegos et al., 1993; Short et al., 1993; Gallegos et al., 1994). However, population growth rates for seagrasses range widely among geographic regions and recovery rates depend on the severity of the injury. Therefore, we have recently completed several experiments that provide the requisite data for a frequently injured seagrass ecosystem, *Syringodium filiforme*, in the FKNMS (Sargent et al., 1995).

To calculate the required compensation under HEA we estimated the time it takes for the injured resources to recover to the pre-injury baseline. For the same reasons that seagrass density was previously chosen as a metric for planting performance (Fonseca, 1994), we elected to use short-shoot density as the metric for assessing recovery.

We began to develop our model approach using a recently injured *S. filiforme* meadow in the FKNMS, a seagrass species that, like *H. wrightii*, has a comparatively high population growth rate compared with the target species, *T. testudinum* (Fonseca et al., 1987). Using these faster-spreading species was critical for us in order to develop and calibrate our modeling approach within a short time (3 years). In addition, this injury was operationally quite similar to the compressed succession approach taken in Section 2, not only because *S. filiforme* also spreads much more quickly than *T. testudinum*, but because it performs a facilitation role for *T. testudinum* recovery similar to that of *H. wrightii*.

In the example we are presenting here, between 25 and 50% of the surface sediment layer was removed by the injury event, leaving only 10–20 cm of unconsolidated sediment in the injury area. This degree of sediment disturbance was thought to affect seed abundance, and it is known that the growth and development of some seagrasses is limited by sediment depth (Zieman, 1972). Thus, because of the severity of the injury we found it necessary to collect in situ data on recovery dynamics to supplement literature values and to calibrate model predictions with actual recovery rates. To accomplish this, we established permanent stations at three sites along the extent of the injured area and in the adjacent undisturbed side population (USP), where we obtained population data for *S. filiforme* short-shoot density, short-shoot demography, apical meristem density, horizontal rhizome growth rates, vegetative reproduction rates, and apical branching rates (Kenworthy and Schwarzschild, 1998). The three sites were sampled at least twice annually for 4 years.

Because *T. testudinum* grows so slowly, we derived short-shoot abundance data by sampling the USP. Population growth data for the model was obtained from our previous research and other literature, with the initial assumption that recovery was based solely on asexual reproduction. Rates of horizontal rhizome growth, production of new apicals, production of new short-shoots, and natural mortality for *T. testudinum* were determined from an exhaustive review of the literature (Patriquin, 1973; Fonseca et al., 1987; Duarte and Sand-Jensen, 1990; Duarte, 1991; Tomasko et al., 1991; Gallegos et al., 1993; Durako, 1994). The immigration of *T. testudinum* rhizome apical meristems into the injury was modeled in the same manner as *S. filiforme*, but slight differences in plant morphology required modifications to the *S. filiforme* model structure. Apical meristem densities in the injury were set assuming the same proportion of apical meristems to short-shoot per square meter in the USP. We also collected data on seedling abundance of both *S. filiforme* and *T. testudinum* in order to refine the model and determine the relative contributions of seed and vegetative recruitment to recovery.

We constructed deterministic population dynamics models of both *S. filiforme* and *T. testudinum* recovery in STELLA II software (High Performance Systems Inc., Hanover, NH) operating on a Macintosh Personal Computer. Although *T. testudinum* was the target species, modeling the faster-spreading *S. filiforme* provided an important model validation step given the time constraints imposed in Section 2. The model was constructed to predict the recovery of short-shoot densities, rhizome apical meristems, and other population characteristics on a square meter basis within the injury area. In its present configuration, the model contains stocks (populations) of rhizome apical meristems (primary apicals and branch apicals) in the injury and in the adjacent USP of *S. filiforme* and *T. testudinum*. Division of the rhizome apical meristem is the fundamental process that forms new shoots and causes growth of horizontal internodes in rhizomatous clonal plants. Thus, rhizome apicals are the major source of vegetative reproduction and horizontal expansion for most seagrasses (Tomlinson, 1974), and were identified as the primary means of recovery in the injury. This assumption was confirmed for *S. filiforme* during initial sampling of the injury 1 year after the disturbance when we recorded densities of 1.2–6.6 seedlings m^{-2} versus rhizome apical densities of 15.6–28.1 m^{-2}. Less than 25% of the seedlings observed had begun vegetative reproduction; and most were only single shoots. In contrast, the rhizomes of *S. filiforme* immigrating from the adjacent USP were spreading and branching vigorously, indicating that the initial stage of recovery was heavily dependent on recruitment from the USP. Likewise, we estimated there were 0.26 *T. testudinum* seedlings per m^2, a minor component of recovery.

4.1. Model predictions — Syringodium filiforme

Model output was generated to predict the number of short-shoots per square meter in the injury over a 10-year period after the injury (Fig. 2a). We validated the output by sampling the three sites in 2, 3, and 4 years after the injury. For the *S. filiforme* model, predicted short-shoot densities in the injury reached the approximate mean density of the USP after about 3 years. In 3.5 years the predicted density exceeded the measured mean density (2161 vs. 2045) and then stabilized, reaching a steady state population of short-shoots in approximately 6–7 years. Although the model accurately predicted that the injury would recover to ambient shoot density in the USP in approxi-

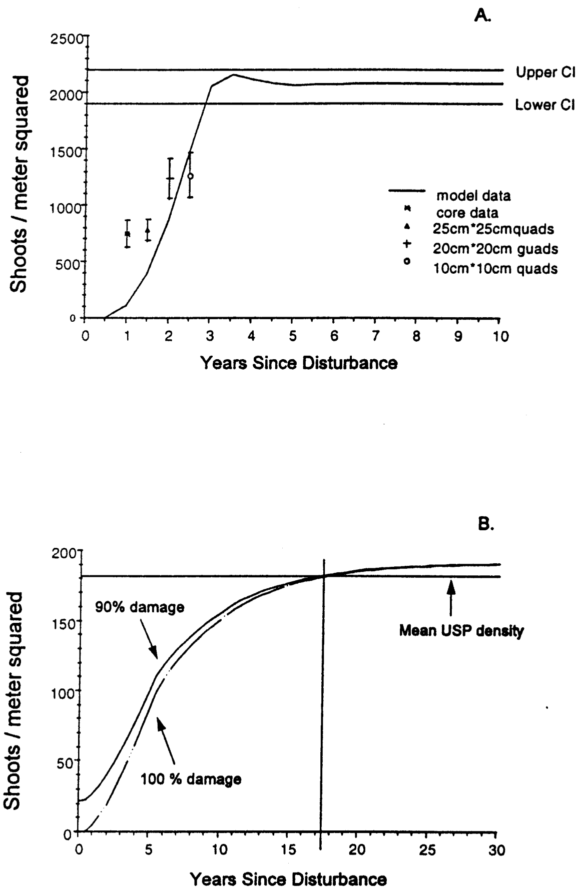

Fig. 2. Results of the STELLA II model predictions for *S. filiforme* (top panel) and *T. testudinum* (bottom panel) recovery. Top panel shows the horizontal lines that represent the 95% confidence intervals around the average density of *S. filiforme* short-shoots in the undisturbed population. Also shown short-shoot densities are in the injury over a 2.5-year interval based on core and quadrat samples. Bottom panel shows the predicted recovery horizon in the injury for *T. testudinum* under two damage scenarios and the mean density of *T. testudinum* short-shoots in the USP.

mately 3 years, it underestimated the overcompensation response of the short-shoot density observed in the injury population.

4.2. *Model predictions* — Thalassia testudinum

To compute the initial values for each stock component (primary apicals, branch apicals, and short-shoot age classes) of the *T. testudinum* model under the damage scenario, the model was initially run for a 50-year period assuming an initial population in the injury of 0 (100% damage). The model population was allowed to reach a stable equilibrium and the relative number of primary and branch apicals and the percentage of short-shoots in each age class were recorded. We also ran the recovery model assuming 90% damage in order to examine its performance as compared with the 100% injury scenario. These values were then entered into the model as initial conditions and the model was run to determine the number of years for the complete recovery. We normalized the short-shoot density in a given year as a percentage of the ambient baseline short-shoot density and used that as a proxy for percent services lost. This formed the curve defining area B (Fig. 1), whereas area A in Fig. 1 was determined by the review of literature and best professional judgment.

The results of these model runs predict that recovery to the mean short-shoot density in the USP requires approximately 3 years for the comparatively faster-growing *S. filiforme* (Fig. 2a) but 17.5 years for the slower-growing *T. testudinum* (Fig. 2b) in the case of 100% injury, meaning that after 17.5 years the age structure and apical to short-shoot ratio of *T. testudinum* in the injury were similar to those observed in the USP. An initial injury of 90% suggested a similar time to complete recovery, indicating that a much larger portion of the original short-shoot population than 90% would have to be left intact in order for more rapid recovery to occur.

In Section 2, two factors contribute to a replacement ratio less than one. The first is that the injured area is expected to recover over time. If this area had been lost in perpetuity, the replacement ratio would have been greater than one, since the total amount of restoration required would have been 1.63 acres to replace the services provided by the permanently injured habitat, plus additional acreage to account for the interim losses in the period prior to the implementation of restoration and in the post-restoration period prior to the restored habitat reaching full maturity (i.e. maximum service provision). The second factor relates to the specific estimated recovery and maturity horizons for the injured and restored habitats, respectively. Because of the long recovery horizon, many of the total service losses occur far in the future. In the present value calculation, these losses are weighted less heavily than losses occurring closer to the present time (Julius, 1997). Conversely, the compensatory restoration project is expected to provide a large percentage of its maximum annual service flow soon after the completion of the project. These early year benefits are weighted more heavily in the present value calculations than benefits occurring far in the future. Thus, in this example, the combination of expected recovery of the injured resource, plus the greater weight given to early term benefits than late term losses, results in a replacement ratio less than one. Again, this is predicated upon our assertion that the present value of those services provided far in the future is less than the value of the same level of services provided today, and that present-day values are what should drive the restoration process. Therefore, the project goals were set at 1.55 acres and the previously established performance criteria were applied to formulate the overall definition of project success.

5. Future directions

Although the wedding of basic biological information (recovery functions) with economic principles (discounting services) has yielded a reasonable and predictable means of assessing a party's level of responsibility, thereby setting fair and consistent restoration goals, new issues are emerging regarding the application of the HEA. For example, a recent study (Fonseca et al., submitted), revealed that the placement of a dredged material island among the patchy seagrass beds located in a wave-swept portion of Southern Core Sound, North Carolina, lowered the wave energy on the lee side of the island and promoted a shift in seagrass cover from $\sim 15\%$ bottom cover to over 60% cover. Using simple extent or shoot density as a measure of seagrass impact, the direct loss of seagrass by creation of the island may have been offset to some degree by an increase in cover at similar densities through the coalescence of patchy beds in the lee. The question is, does this offset constitute built-in mitigation? Other issues, such as up-front mitigation trade-offs between animal communities that might use patchy versus more continuous cover (i.e. functional differences among seagrass habitats), should be considered. However, future studies will need to consider the degree to which (if any), modification of fragmented seagrass beds may provide some kind of inherent mitigative function by increasing local percent cover of the seafloor by seagrass as an offset to habitat injuries. In general, this example reveals the importance of incorporating other habitat attributes, such as landscape characteristics, into our evaluation of the true equivalency of the selected compensatory project as compared with the injured area.

6. Conclusions

Computations of interim loss have often been divorced from ecological relevance, and consequently replacement ratios have not been sufficiently quantitative to provide predictable standards for setting performance criteria, compliance, and, ultimately success. New, economically based models provide a means of standardizing the interim loss computation. When coupled with mensurative experimental data, this method has been shown, through successful litigation, to provide a reasonable basis for documenting injury, setting goals, and gauging restoration success.

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