Assessing anthropogenic injury, modeling recovery, computing lost interim services and scaling compensatory action in seagrass ecosystems

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Groundings of vessels in the shallow areas of the Florida Keys National Marine Sanctuary (FKNMS) are reported to exceed 500 cases a year and is the cause for the deterioration of over 12,000 ha (~2% of the total resource) in this area. Under the legislation authorizing the creation of such Sanctuaries, the Government may levy fines to compensate for lost to trust resources. Therefore, to respond to these groundings, a team has been created that: 1) responds to groundings and creates spatially explicit maps of the grounding footprint, 2) models the recovery rate based on the intrinsic recovery rate of the injured seagrass and both the extent and geometry of the injury, 3) computes a restoration-based assessment of costs and required acreage that must be restored to compensate for interim loss of resource services (Habitat Equivalency Analysis - HEA), and 4) provides the legal framework for execution of claims recovery. In this paper, I will outline the aforementioned processes, detailing the HEA and spatial modeling methods that were developed in order to provide a fair and reasonable assessment of injuries to seagrass beds (particularly to very old *T. testudinum)* in the in order to recoup damages from the Responsible Parties. The genesis of success criteria will be discussed (focus on persistence, acreage, and habitat quality, e.g. shoot density), as will computation of replacement ratios using economic tools and the intrinsic recovery rate of the injured seagrass beds themselves as compared to the efficacy of the restoration itself. Based on field surveys of the recovery of injured seagrass beds in the FKNMS, HEA was used to determine the lost on-site services pertaining to the ecological function of an area as the result of an injury. This loss of services is set against the difference between intrinsic recovery and recovery afforded by restoration, providing a measure of the area that must be restored. Finally, I will present: 1) the background information needed to scale the results

of injury geometry modeling to real-world recovery rates, and 2) an operational description of the two modeling procedures (deterministic and stochastic), 3) the effects of varying injury geometry on the recovery function, and 4) a comparison of the two models in a Case Study regarding an actual grounding event.

Hydrodynamics and the forecasting of Ecological Characteristics of Seagrass Ecosystems

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Disturbance in the forms of waves (both wind and vessel-generated) and tidal currents controls distribution and spatial organization of seagrass beds. Conversely, while hydrodynamics modify seagrass, seagrasses in turn, modify hydrodynamics, resulting in local alteration of water motion, sediment deposition, animal abundance and distribution and stabilization of shorelines. Moreover, these disturbances have markedly limited the success of seagrass restoration. We have seen that tidal current speeds, exposure to waves and relative water depths are strongly correlated with features of seagrass beds. Some habitat attributes such as percent cover of seagrasses, seagrass bed perimeter to area ratio, sediment organic content and percent silt-clay declined with increasing REI and current speed. Moreover, we hypothesize that an observed critical threshold of seagrass cover near the ~50% coverage level occurs as the result of habitat fragmentation and the loss of physical integrity of the entire landscape. To better forecast these relationships, we began in 1996, began to develop a model (*sensu* Keddy 1982) that would describe the impact of wind-generated waves on the distribution of subtidal seagrass patches within an estuarine landscape. The model, developed using the advanced macro language (AML) associated with ARC/INFO, first calculated a Relative Exposure Index (REI) using measures of effective fetch (F), wind speed (V), and wind duration (P):

$$REI = \sum_{i=1}^{8} (V_i \times P_i \times F_i)$$

This form of model, while appropriately tuned for North Carolina, failed to consistently predict seagrass landscape patterns when exported to the Chesapeake Bay. Therefore, the model has gone through several iterations to incorporate not only effective fetch, wind speed and wind duration, but also bathymetry. To achieve this an inverse distance weighted procedure incorporating bathymetric topology is used to calculate bathymetrically-weighted effective fetch (idwF). A further refinement has been achieved by weighting idwF using tidal emersion (T) duration at each sampling site.

$$REI = \sum_{i=1}^{8} [(V_i \times P_i \times (idwF_i \times T_i)]$$

This new model has been applied to Yaquina Bay, a small drowned river estuary located on the outer coast of Oregon. A visual comparison of SAV (submerged aquatic vegetation) distribution digitized from 1997 orthorectified color infrared aerial photographs and SAV distribution portrayed by our model suggests that this version of the model predicted seagrass distribution that closely matched the observed distributions. With further development, this model may provide a parsimonious vehicle that will enable both hindcasting and forecasting trends in seagrass landscape structure and function. Our goal is to produce products that predict: 1) the probability of seagrass habitat cover; 2) the probability of seagrass habitat lost to acute storm events; and 3) probable sites for regrowth given some level of disturbance (*e.g.* restoration). Each of these products contains explicit information required for managers that could not be derived from a traditional mapped product. With this analytical tool we can now begin to predict the kind of seagrass habitats that may develop in the area as the result of restoration, their faunal components, and through hindcasting of storm event data, the susceptibility of these beds and the shoreline property they protect to storm events.