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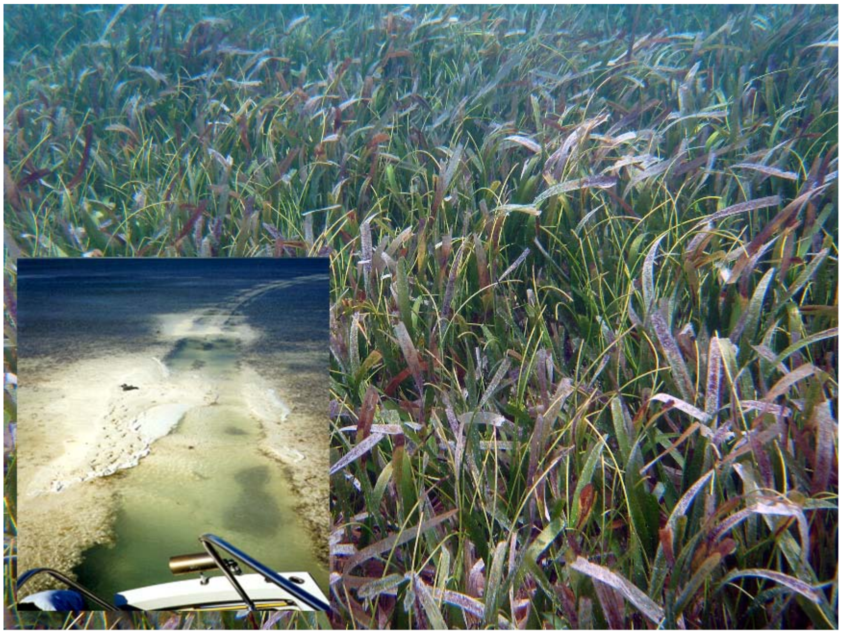

Preliminary Comparison of Natural Versus Model-Predicted Recovery of Vessel-Generated Seagrass Injuries in Florida Keys National Marine Sanctuary

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Ocean Service
Office of Ocean and Coastal Resource Management
Office of National Marine Sanctuaries

July 2009

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Preliminary Comparison of Natural Versus Model-Predicted Recovery of Vessel-Generated Seagrass Injuries in Florida Keys National Marine Sanctuary

A. V. Uhrin, M. S. Fonseca, and W. J. Kenworthy

NOAA/NOS Center for Coastal Fisheries and Habitat Research (CCFHR), 101 Pivers Island Road, Beaufort, NC 28516

U.S. Department of Commerce
Gary Locke, Secretary

National Ocean and Atmospheric Administration
Jane Lubchenco, Ph.D.
Under Secretary of Commerce for Oceans and Atmosphere

National Ocean Service
John H. Dunnigan, Assistant Administrator

Office of National Marine Sanctuaries
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Silver Spring, Maryland
July 2009

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COVER

Seagrass bed composed of *Thalassia testudinum* and *Syringodium filiforme* (Credit: NOAA).

Inset: Vessel-generated seagrass injury in Florida Keys National Marine Sanctuary (Credit: NOAA).

SUGGESTED CITATION

Uhrin, A. V., M. S. Fonseca, and W. J. Kenworthy. 2009. Preliminary Comparison of Natural Versus Model-predicted Recovery of Vessel-generated Seagrass Injuries in Florida Keys National Marine Sanctuary. Marine Sanctuaries Conservation Series NMSP-09-03. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries, Silver Spring, MD. 13 pp.

CONTACT

Amy V. Uhrin, Research Ecologist
NOAA/NOS Center for Coastal Fisheries and Habitat Research, 101 Pivers Island Road, Beaufort, NC 28516
E-mail: amy.uhrin@noaa.gov

ABSTRACT

Each year, more than 500 motorized vessel groundings cause widespread damage to seagrasses in Florida Keys National Marine Sanctuary (FKNMS). Under Section 312 of the National Marine Sanctuaries Act (NMSA), any party responsible for the loss, injury, or destruction of any Sanctuary resource, including seagrass, is liable to the United States for response costs and resulting damages. As part of the damage assessment process, a cellular automata model is utilized to forecast seagrass recovery rates. Field validation of these forecasts was accomplished by comparing model-predicted percent recovery to that which was observed to be occurring naturally for 30 documented vessel grounding sites. Model recovery forecasts for both *Thalassia testudinum* and *Syringodium filiforme* exceeded natural recovery estimates for 93.1% and 89.5% of the sites, respectively. For *Halodule wrightii*, the number of over- and under-predictions by the model was similar. However, where under-estimation occurred, it was often severe, reflecting the well-known extraordinary growth potential of this opportunistic species. These preliminary findings indicate that the recovery model is consistently generous to Responsible Parties in that the model forecasts a much faster recovery than was observed to occur naturally, particularly for *T. testudinum*, the dominant seagrass species in the region and the species most often affected. Environmental setting (i.e., location, wave exposure) influences local seagrass landscape pattern and may also play a role in the recovery dynamics for a particular injury site. An examination of the relationship between selected environmental factors and injury recovery dynamics is currently underway.

KEY WORDS

Seagrass recovery, vessel groundings, seagrass disturbance, seagrass recovery model, Florida Keys National Marine Sanctuary, Mini-312 Program

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INTRODUCTION

Seagrass beds are an integral component of the south Florida marine ecosystem. Within the boundaries of the Florida Keys National Marine Sanctuary (FKNMS) nearly 1.4 million acres of seagrass function as habitat, settlement sites, nurseries, feeding grounds, and refuge for a large number of ecologically and commercially important marine organisms (Zieman, 1982; Zieman and Zieman, 1989; Fourqurean et al., 2001). Despite the irrefutable significant ecological value of seagrasses, annually more than 500 motorized vessel groundings cause widespread damage to seagrass habitat in the Sanctuary and throughout other regions of Florida (Sargent et al., 1995; Whitfield et al., 2002; Kirsch et al., 2005; SFNRC 2008). Given the growing popularity of the Florida Keys for marine recreation (SCUBA diving, fishing) and commercial fishing, vessel groundings will almost certainly continue to occur.

Vessel groundings are some of the most severe injuries that can occur in seagrass meadows (Kenworthy et al. 2002). A typical grounding results in the formation of at least one of four features: 1) propeller scars (shallow, narrow, linear excavated trenches caused by the propeller while the vessel is still moving), 2) keel scars (usually a depression into the seagrass mat when the keel comes to rest as vessel forward movement halts), 3) blowholes (deep, large excavations caused by propeller wash as the vessel becomes hard aground or the operator attempts to power off) and, 4) berms (excavated material deposited on the outskirts of blowholes). Grounding events directly remove above- and belowground seagrass biomass resulting in features that are highly vulnerable to storm events. For example, Whitfield et al. (2002) reported how storms caused expansion of injuries by up to 135% of the original area. Given the slow recovery rates exhibited by the most frequently injured seagrass species (*Thalassia testudinum*) in the FKNMS (2 – 10 years for propeller scars in *Thalassia testudinum:* Zieman 1976, Durako et al. 1992, Dawes et al. 1997, Kenworthy et al., 2002) and the often cumulative nature of vessel groundings, these injuries severely alter both short and long-term seagrass ecosystem functions (Sargent et al. 1995, Uhrin and Holmquist 2003, SFNRC 2008). Moreover, multiple injuries to a seagrass bed create a scenario where the loss of seagrass cover can lead to a state change, shifting what was a seagrass bed to a sparse or non-vegetated state following a storm event (Fonseca and Bell 1998, Fonseca et al. 2000a).

Under Section 312 of the National Marine Sanctuaries Act (NMSA), any person responsible for the loss, injury, or destruction of any Sanctuary resource is liable to the United States for response costs and resulting damages and restoration. The two governing agencies, the National Oceanic and Atmospheric Administration (NOAA) and the Florida Department of Environmental Protection (FDEP), co-operatively conduct injury assessments and develop restoration plans for vessel injuries to seagrass resources utilizing protocols and analyses established under the auspices of the Mini-312 Program (NOAA; Fonseca et al., 2000b; Fonseca et al., 2004; Kirsch et al., 2005). Field impact assessments include site mapping and bathymetric surveys using high resolution Differential Global Positioning Systems (DGPS) and fathometers, as well as characterization of injured habitat by visual assessment methods (Kirsch et al., 2005).

Field data, specifically the spatially articulated injury perimeter measurements, are input to a recovery model which uses published data on seagrass growth rates combined with injury geometry to compute a recovery trajectory (Fonseca et al., 2004). Restoration plans include recommendations for primary restoration (restoration activities within the actual grounding site) and compensatory restoration (off-site restoration activities to compensate for lost interim ecological services). The level of primary and compensatory restoration is determined through a Habitat Equivalency Analysis (HEA) which incorporates the recovery model output and economic discounting (NOAA, 1997; Fonseca et al. 2000b).

Given that natural recovery may take place under suitable conditions, the ability to forecast whether or not an injury could potentially recover without intervention or with minimal restorative action would enable management to focus efforts on those sites where recovery is less likely. The need to validate the model recovery predictions is critical. Prior to this report we had been unable to conduct a comparison of our recovery model with what was actually transpiring at the injured sites. To that aim, we reassessed 30 Mini-312 grounding incidents where restoration had yet to be implemented. At each of the sites we examined the change in area of blowhole features as well as the change in percent cover of seagrass within blowholes. We compared recovery trajectories generated from the recovery model to the observed natural recovery at each site to validate model performance.

METHODS

Site Selection

In March 2004, we consulted the NOAA Damage Assessment Center (DAC) database of reported seagrass vessel grounding sites in FKNMS and chose a subset of sites where restoration had yet to be executed. The widespread geographic distribution of grounding sites in FKNMS made it necessary to limit the number of sites to a manageable subset. We considered injury age (e.g. passage of time) to be highly influential in the recovery process as it has been shown that seagrasses will grow and re-colonize an area where they previously existed given enough time, and barring further disturbance (Thayer et al. 1994). Thus, the available sites were initially grouped using the inter-quartile ranges (IQR) for injury age, calculated using PROC UNIVARIATE in SAS Version 9.1 (SAS Institute, Inc. 2002). Within each of the four age quartiles (< 1.43 years, 1.43-1.95 years, 1.96-2.88 years, and 2.89-6.33 years), sites were further categorized according to relative wave exposure (RWE). RWE was determined by applying the Wave Exposure Model (WEMo; Malhotra and Fonseca 2007) to each injury for the time period beginning from the date of the first injury assessment through present day. RWE was chosen as an initial categorization variable due to its strong link with seagrass landscape pattern (Patriquin 1975, Fonseca and Bell 1998, Kendrick et al. 2000, Fonseca et al. 2002, Krause-Jensen et al. 2003, Frederiksen et al. 2004) and the influence of hydrodynamics in general on seagrass recovery (Kirkman 1985, Kendrick et al. 2000, Whitfield et al. 2002). RWE categories were generalized as follows: < 10000, 10001-20000, and > 20000. The initial categorization of sites in this manner strictly served as a mechanism to achieve a representative subset of sites but was not used for statistical analyses Within each age x RWE combination, it was our desire to obtain a minimum of three representative grounding sites. In some instances this was not possible due to the absence or limited numbers of sites meeting those criteria. In the end, a total of 30 sites were selected for investigation.

Initial Field Assessments

The 30 grounding sites had previously been assessed by DAC staff (typically within two weeks of the grounding incident) using established, quantitative techniques (Kirsch et al., 2005). Each grounding site was mapped by physically tracing the outline of the injury features using DGPS. Depending upon the depth of water over the injury features, the DGPS unit was either handheld and the outlines traced by walking the injury perimeter or mounted on an inflatable boat which was then floated around the perimeter under the guidance of a snorkeler. Injury feature coordinates (WGS84 datum) were downloaded to Trimble GPS Pathfinder® Office software and then exported to ESRI's ArcView® software for calculation of injury area (square meters) using the UTM83 – Zone 17N coordinate system.

Replicate $0.25m^2$ quadrats were haphazardly tossed into each injury feature and in the surrounding undisturbed seagrass meadow and the cover of vegetation was visually inspected. Seagrass, macroalgae, and coral present in the quadrats were identified and assigned a cover-abundance scale value: 0 = not present, 0.1 = solitary specimen, 0.5 = few specimens (< 5), 1 = numerous but no more than 5% cover, 2 = 5 to 25% cover, 3 = 26 to 50% cover, 4 = 51 to 75% cover, and 5 = greater than 75% cover. A minimum of three quadrats were sampled from within each injury feature (a function of injury size) and a minimum of 10 from the undisturbed reference area taken within 1-3 m of the injury features. Care was taken to collect reference samples from around the entirety of the injury perimeter to account for habitat heterogeneity in the reference bed.

Revisit Field Assessments

During the summer of 2004 and spring of 2005, each of the 30 injury grounding sites were revisited and reassessed duplicating the aforementioned DAC protocol. The time-lapse between initial assessment and re-assessment resulted in site ages ranging from 1.43 – 3.46 years. To quantify seagrass re-colonization (recovery) within blowholes, the original blowhole perimeter was uploaded into the DGPS, re-traced, and marked with survey flags. Braun-Blanquet quadrats were then sampled from within the original blowhole perimeter utilizing the same level of replication as in the initial field assessment. If there was a change in the perimeter of the original injury feature, a new injury outline was mapped by delineating the perimeter of the currently existing bare substrate.

Natural Recovery Estimates

From the original Braun-Blanquet cover estimates at each site, the following Density (D) statistic was calculated for each blowhole, by seagrass species, and for total seagrass present:

$$D_i = \sum_{j=1}^{n} S_{ij} / n$$

where D_i = density of species i; j = quadrat number from 1 to n, the total number of quadrats sampled per injury feature; and S_{ij} = the Braun-Blanquet score for species i in quadrat j (Kenworthy et al., 1993; Fourqurean et al., 2001). The Density statistic was used to calculate percent natural recovery of seagrass for each blowhole feature, by seagrass species as follows:

$$\%\ \text{Recovery} = (D_{ic} / D_{ir}) \times 100$$

where D_{ic} = density of species i from control samples c taken at the time of injury occurrence and D_{ir} = density of species i from reassessment samples r taken from directly within the original injury perimeter. Here, D_{ic} represents the pre-injury baseline, assumed to be static, and thus, the final desired endpoint of restoration.

Model Recovery Estimates

A cellular automata modeling technique was used to formulate injury recovery trajectories for each site (Fonseca et al., 2000b; 2004). The model used an iterative process whereby each iteration of the model represented a time step of one year and yielded a grid that continually filled with occupied cells until all cells were designated as being occupied. The percentage of the injury that had recovered and the remaining years to complete recovery were calculated at each time step for *Thalassia testudinum* and *Syringodium filiforme* / *Halodule wrightii* combined. Percent recovery was then plotted by time in years to derive the recovery horizon for the entire injury. The resulting regression equations were used to calculate the expected percent recovery for each injury based upon the actual age of the injury. We then compared the predicted percent recovery to that which was observed to be occurring naturally.

RESULTS

All 30 sites had *Thalassia testudinum* present in the reference quadrats; however, we were unable to run the model for one site, due to discrepancies in the collection of the field data, therefore, N = 29. The model over-predicted *T. testudinum* recovery for all but two sites (93% of the time), with an average over-prediction difference of ~24% (Figure 1).

Of the 19 sites that had *Syringodium filiforme* present in the reference seagrass bed, the model over-predicted recovery 89.5% of the time (17 of 19 sites) with an average over-prediction difference of ~73% (Figure 1).

Halodule wrightii was present in reference samples from 11 of the 29 sites. Of these 11, the model over-predicted recovery for 6 sites with an average over-prediction difference of 76.4% (Figure 3). For the remaining five sites where recovery was under-estimated, the difference was much more extreme with an average under –prediction difference of 160% (Figure 1).

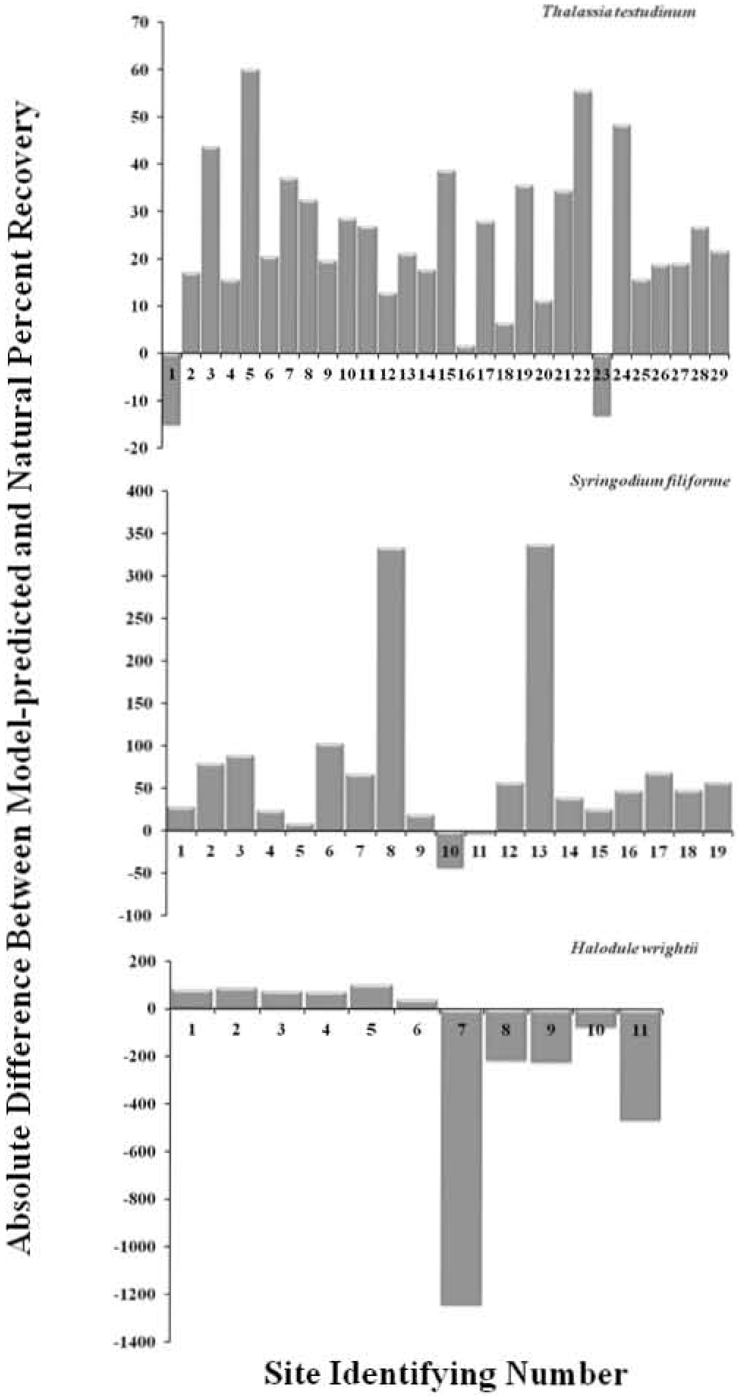

Figure 1. Absolute difference between model-predicted and natural percent recovery of selected vessel grounding sites in Florida Keys National Marine Sanctuary. Positive differences indicate model over-prediction while negative differences indicate under-prediction.

DISCUSSION

To our knowledge, these data represent the first quantitative post-hoc validation of the injury recovery model currently employed by NOAA for seagrass injury assessment. These preliminary findings indicate that the recovery model is consistently generous to Responsible Parties in that the model forecasts a much faster recovery than was observed to occur naturally, especially for *T. testudinum* and *S. filiforme*. It was very important to document whether *T. testudinum* was being fairly assessed given that the inherently slow growth rate of this species contributes far more heavily to computations of lost interim services under HEA (Fonseca et al., 2000b). Therefore, the application of the cellular automata model has thus far resulted in over-estimation of the recovery rate and under-estimation of lost interim services resulting in lower dollar amounts in claims cases against the Responsible Party as well as lowered funds for restoration efforts. Fonseca et al. (2004) and Kirsch et al. (2005) suggested that aspects of the model would likely lead to over-estimation of recovery because the injured area was considered to be fully conducive to recovery (i.e., the sediment was level with the surrounding un-impacted seagrass; Hammerstrom et al. (2007) demonstrated that as little as 20cm of sediment loss could inhibit *T. testudinum* re-growth). Another attribute of the modeling approach not previously mentioned is that each injury polygon is allowed to recover with seagrass at all edges. In reality, many injuries have blowholes and berms adjacent to each other so that no seagrass recovery source is available for long portions of the injury edge. Additionally, the model currently does not consider the recovery of below-ground biomass which is often more severe than losses to the above-ground component and requires considerably more time to fully recover (Di Carlo and Kenworthy, 2008).

Under-estimates of recovery for *H. wrightii* tended to be large when they occurred. This is not surprising given the opportunistic nature of this species and its capacity to rapidly colonize an area (Fonseca et al., 1987; Gallegos et al., 1994; Kenworthy et al., 2002; Uhrin et al., 2009). The rapid natural recovery rate for this species indicates that injury to *H. wrightii* beds would have comparatively low restoration costs (*sensu* Fonseca et al., 2004). Primary restoration protocols in the Mini 312 Program capitalize on this functional characteristic of *H. wrightii* by prescribing the planting and fertilization of this species to rapidly stabilize sediments and contribute to the establishment of a functional seagrass habitat (“compressed succession” Derrenbacker and Lewis, 1982; Fonseca et al., 1987; Kenworthy et al., 2000). Here, compressed succession initiates the long-term (decades) return of what is most often the primary shallow water seagrass species in FKNMS, *Thalassia testudinum*.

Ongoing analysis is underway to attempt to isolate environmental factors influencing natural recovery of these injuries. From previous studies, the influence of site exposure to waves seems to indicate that the open gap created by a blowhole will increase in size with extreme event wave energy as seen with storm impacts to patchy seagrass and injured seagrass beds elsewhere (Fonseca et al., 2000a; Whitfield et al., 2002). We will continue to examine this response to determine whether the particular location of an injury site has a storm-related or even just ambient wave energy exposure that would influence the local seagrass landscape pattern (*sensu* Fonseca and Bell 1998) or might trigger priority restoration action to prevent further injury.

However, we can conclude at this point that the injury recovery modeling approach that has been adopted for use in the Mini-312 Program is over-estimating recovery to the benefit of the Responsible Party in injury cases that are dominated by *T. testudinum*. No decisions have been reached as to whether the modeling process will be revised.

ACKNOWLEDGEMENTS

This study was funded by NOAA's Damage Assessment Center as well as additional direct support from the National Centers for Coastal Ocean Science. This work would not have been possible without field and technical support from K. Kirsch, S. Meehan, A. Simonti, and A. Farrer. We also recognize M. Edson, G. DiCarlo, J. Hackney, G. Piniak, and J. Vander Pluym for field assistance and D. Johnson, P. Marraro, G. Piniak, M.E. Rolle, J. Schittone, A. Stratton, and L. Symons for comments that improved the manuscript.

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Automated, objective texture segmentation of multibeam echosounder data - Seafloor survey and substrate maps from James Island to Ozette Lake, Washington Outer Coast. (NMSP-07-05)

Observations of Deep Coral and Sponge Assemblages in Olympic Coast National Marine Sanctuary, Washington (NMSP-07-04)

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