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Seagrass ecosystem trajectory depends on the relative timescales of resistance, recovery and disturbance

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ABSTRACT

Seagrass ecosystems are inherently dynamic, responding to environmental change across a range of scales. Habitat requirements of seagrass are well defined, but less is known about their ability to resist disturbance. Specific means of recovery after loss are particularly difficult to quantify. Here we assess the resistance and recovery capacity of 12 seagrass genera. We document four classic trajectories of degradation and recovery for seagrass ecosystems, illustrated with examples from around the world. Recovery can be rapid once conditions improve, but seagrass absence at landscape scales may persist for many decades, perpetuated by feedbacks and/or lack of seed or plant propagules to initiate recovery. It can be difficult to distinguish between slow recovery, recalcitrant degradation, and the need for a window of opportunity to trigger recovery. We propose a framework synthesizing how the spatial and temporal scales of both disturbance and seagrass response affect ecosystem trajectory and hence resilience.

1. Introduction

Found at the interface between the land and the sea, seagrasses act as ecosystem engineers by stabilizing sediment, taking up nutrients, storing carbon and providing habitat for fish and other marine fauna (Bos et al., 2007; Jones et al., 1994; Mcleod et al., 2011). The feedbacks and interactions between seagrass and various biotic and abiotic factors can buffer against stressors, and generate many valuable ecosystem services (Duarte, 2002; Orth et al., 2006a). Seagrass presence can improve conditions for seagrass growth, for example through sediment stabilization, nutrient uptake and sheltering mesograzers (Maxwell et al., 2016). Ironically these feedbacks can also act as a barrier to

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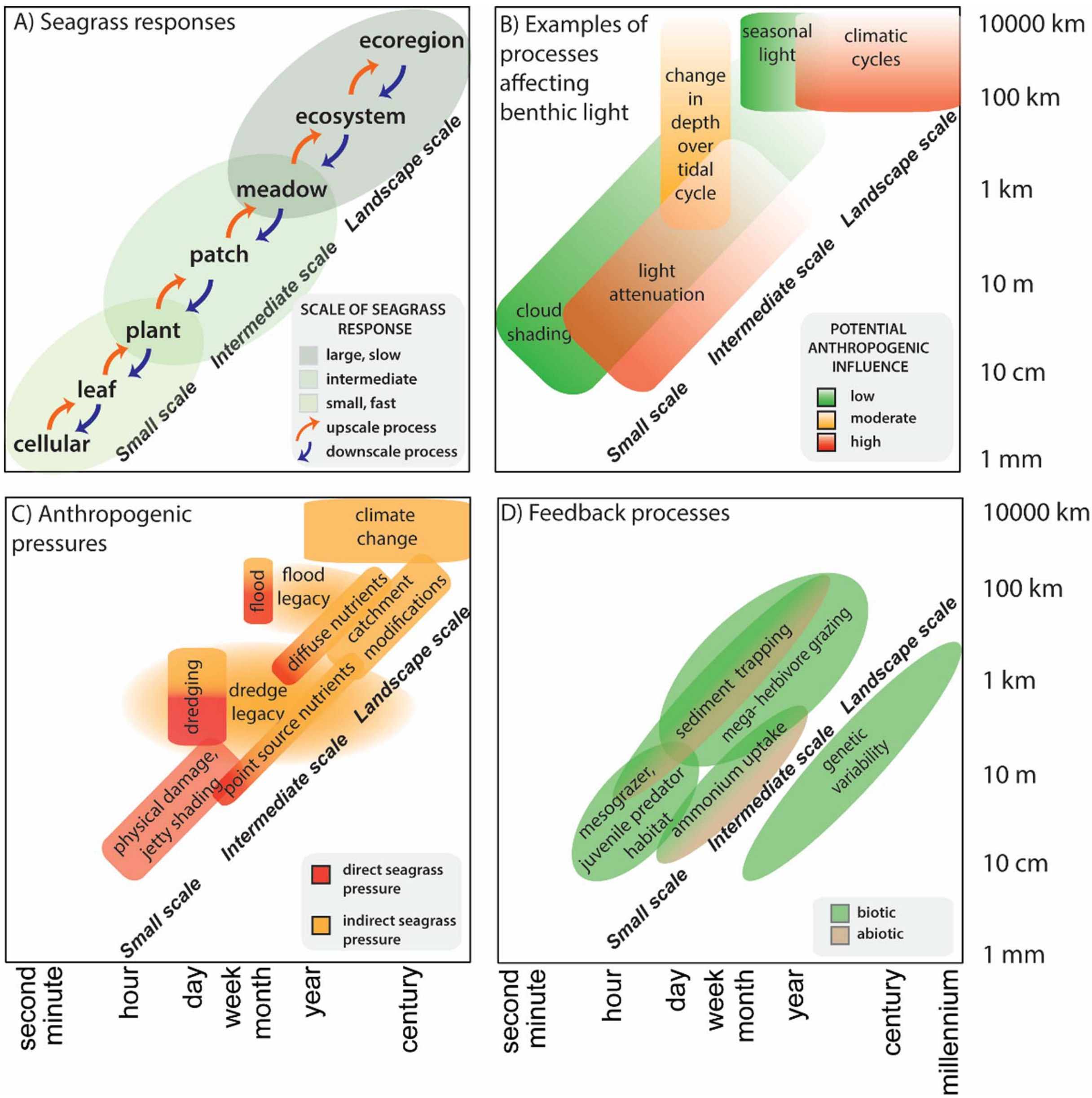

Fig. 1. Seagrass ecosystems are affected by spatial and temporal variability in A) seagrass responses, grouped here as small & fast, intermediate or large & slow. Upscale and downscale processes (red and blue arrows respectively) represent responses at one scale which accumulate to cause changes in processes at higher or lower scales respectively; B) natural processes, for example factors affecting benthic light; C) anthropogenic pressures and D) feedbacks. Full references in Tables S1-S4. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

recovery: in some cases, the absence of seagrass can render benthic light and sediment stability too low for recolonization (Carr et al., 2010; Nyström et al., 2012; van der Heide et al., 2007; van Katwijk et al., 2009).

The habitat requirements for seagrass have been well characterized, for example as minimum light requirements (Dennison, 1987; Duarte, 1991b), maximum water and current velocity (Cabaço et al., 2010; Infantes et al., 2009), optimum temperature (Adams et al., 2017), and in various seagrass distribution models (e.g. Adams et al., 2015; Grech and Coles, 2010). However seagrass response to environmental change is much more difficult to quantify. Numerous empirical studies have shown that seagrass dynamics are affected by interactions between environmental variables, such as temperature, light and the density and diversity of grazers (Christianen et al., 2012; Collier et al., 2016; Duffy et al., 2003; Eklöf et al., 2010; Heithaus et al., 2014), however these relationships are complex, and laboratory or field manipulations are unable to assess interactions between all variables. Simple mathematical models demonstrate that self-sustaining feedbacks have the potential to perpetuate either seagrass presence or absence (Carr et al., 2012; Maxwell et al., 2016; Maxwell et al., 2015), but again these models necessarily account for only a small number of processes which affect seagrass dynamics. Large biogeochemical models are able to include more factors, e.g. Baird et al. (2016), but typically cannot include feedbacks by which seagrass influence environmental conditions (Adams et al., 2016) and rely on limited empirical data for parameterization (Adams et al., 2017). Furthermore, as in other environmental systems, the predictive capacity of deterministic models is constrained by limited spatial and temporal resolution of input data (Levin et al., 2012; Oreskes et al., 1994). While a multitude of seagrass indicators exist, no single indicator can provide an overall assessment of condition across a range of scales (Irving et al., 2013; McMahon et al., 2013; Roca et al., 2016). Many indicators are limited in scope outside the specific purpose for which they have been developed, and the relationship between current seagrass state and future condition is