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Cover versus recovery: Contrasting responses of two indicators in seagrass beds

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ABSTRACT

Despite being a highly valuable key-stone ecosystem, seagrass meadows are threatened and declining worldwide, creating urgent need for indicators of their health status. We compared two indicators for seagrass health: standing leaf area index versus relative recovery from local disturbance. Disturbance was created by removing aboveground biomass and recording the rate of regrowth for *Zostera marina* meadows exposed to contrasting wave regimes and nutrient stress levels.

Within the experimental period, relative regrowth in gaps was around 50% in most plots, except for the ambient nutrient treatment at the sheltered site, where it exceeded 100%. The two indicators showed an opposite response to disturbance: the higher the standing leaf area index, the lower the relative recovery from disturbance. This conflicting response raises the question on the proper interpretation of such indicators to estimate seagrass health and resilience, and how to ideally monitor seagrass ecosystems in order to predict collapse.

1. Introduction

Seagrasses represent one of the most valuable resources in the coastal landscape for the ecosystem services they provide. Seagrass meadows can be found in coastal areas worldwide, are defined as keystone species (Zieman et al., 1999) and are known to be highly sensitive to environmental status (Orth et al., 2006). Their development and distribution depend on various conditions such as light and nutrient availability (Duarte, 1991; Grice et al., 1996; Wicks et al., 2009), sufficiently sheltered hydrodynamic conditions and low sediment dynamics (Koch, 2001; Eriksson et al., 2010). Despite their capacity to adapt and to cope to some extent with environmental changes, seagrasses suffer rapid and large-scale losses worldwide, their distribution is declining and their survival threatened (Orth et al., 2006). Anthropogenic influences, causing changes in soil chemistry, nutrient loading, hydrodynamics and sediment dynamics are responsible for the seagrass disappearance over the last 40 years (Orth et al., 2006 and references therein; Waycott et al., 2009).

With the rapid loss of seagrasses, monitoring programs were initiated in the last two decades to better estimate the evolution and status of seagrasses (Duarte et al., 2004). For most monitoring programs like *seagrass watch* or *seagrass net*, seagrass density or percent ground cover are commonly used indicators to evaluate a meadow status along transects or quadrats (McKenzie et al., 2003; Duarte et al., 2004; Short et al., 2006). With these measurements, seagrass status can be evaluated by comparing cover maps over defined periods of time and to observe the evolution and status of the meadow (i.e. healthy or in decline). These monitoring programs also use environmental parameters such as water and sediment quality in combination with seagrass measurements to infer the causes of changes in seagrass cover and distribution (Duarte et al., 2004; Short et al., 2006; Neckles et al., 2012).

Several recent studies have argued that seagrass systems follow alternative stable state theory, implying hysteresis in the transition between vegetated and unvegetated states (van der Heide et al., 2007, 2010; Carr et al., 2010, 2012). This has profound effect on the resilience of the system, i.e. the capacity of recovery of the system to its initial state (equilibrium) after a perturbation. According to Holling (1973), resilience refers to the size of the valley, or basin of attraction, around a state, which corresponds to the maximum perturbation that can be taken without causing a shift

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to an alternative stable state (cf. Scheffer et al., 2001). As resilience is a difficult parameter to measure directly, recovery rates from disturbance are used as an indicator. This is based on model explorations (e.g. van Nes and Scheffer, 2007) which showed that at higher stress levels, when the system approaches its tipping point, it will exhibit a slower recovery rate from disturbance. This phenomenon is referred to as 'critical slowing down' (Dakos et al., 2011). It still remains largely unknown whether critical slowing down can be used in practice as an indicator or early warning signal across ecosystems (Hastings and Wysham, 2010). As a matter of fact, the main support for the existence of critical slowing down originates from theoretical models based on long-term data and on specific systems (Boettiger and Hastings, 2013).

As seagrasses are disappearing fast worldwide, there is, in addition to good monitoring programs, need for indicators for their capacity to recover from disturbances. In this study, we aim to find the relationship between (i) a traditionally used *indicator for seagrass health* from global monitoring programs (i.e., seagrass cover) and (ii) a theoretically suggested *indicator for seagrass health in terms of resilience to disturbances* (i.e., critical slowing down). To compare both indicators, we combined vegetation monitoring with a disturbance-recovery experiment by above-ground biomass removal, at two nutrient-stress levels (i.e., ambient versus nutrient enriched) and at two hydrodynamic contrasting field sites (i.e., relatively sheltered versus wave exposed). Sediment nutrient enrichment was used to impose contrasting stress levels within each field site, to which both indicators can respond. Stress differences can be due to creation of eutrophic conditions or by alleviating nutrient limitations. For both nutrient levels, at both sites, disturbance was imposed by removing the above-ground cover by mowing the leaves, as typically occurs due to animal grazing or boat anchoring. Overall we aim to test the hypothesis that the *indicator for seagrass health* (i.e., seagrass cover) and the *indicator for seagrass resilience* (i.e., critical slowing down) give similar response to site-specific conditions and nutrient induced stresses, but may vary in the strength of their response. That is, we compare the correlation between the responses of two indicators (leaf area index, as a quantitative proxy for the generally by experts quickly estimated seagrass cover, for *seagrass health* versus critical slowing down of recovery *for seagrass resilience*) under different interacting environmental settings (i.e., wave exposed versus sheltered and ambient nutrient versus nutrient enriched).

2. Material and methods

2.1. Field sites

Indicators of seagrass health were compared at two sites varying in their exposure to hydrodynamics, located in the Shandong province (China) close to the city of Weihai (Fig. 1). The sheltered site (SS) is located in "Yuehu lagoon" or "Swan Lake" (N37°20′58.2″; E122°34′48.4″) and has a small tidal inlet (86 m wide) and shallow waters (<2 m) all over the lagoon. In contrast, Dongchu Island (N37°02′28.1″; E122°34′11.4″) is a more exposed site (ES) with strong hydrodynamics and a rocky shore open to the sea. Both sites have a dense and healthy *Zostera marina* (Linnaeus, 1753) meadow, which is also exploited for aquaculture in SS (i.e., mainly for sea cucumber and shellfish). Hydrodynamics were not measured during the experiment, but the geographical situation and wind fetch of both sites allowed us to define their relative exposure: a shallow lagoon as SS and an open-sea system with a rocky shore and visible waves on the shore close to the meadow as ES (personal observations). In winter, SS is a refuge for swans migrating from Siberia and eating on the seagrasses but not as their main food (personal communication with local people). The sheltered site is expected to have stronger anthropogenic influences due to its limited water exchange with the open sea and high human population density along the shore.

2.2. Experimental design

A nutrient addition experiment was implemented simultaneously in both ES and SS seagrass meadows at the beginning of

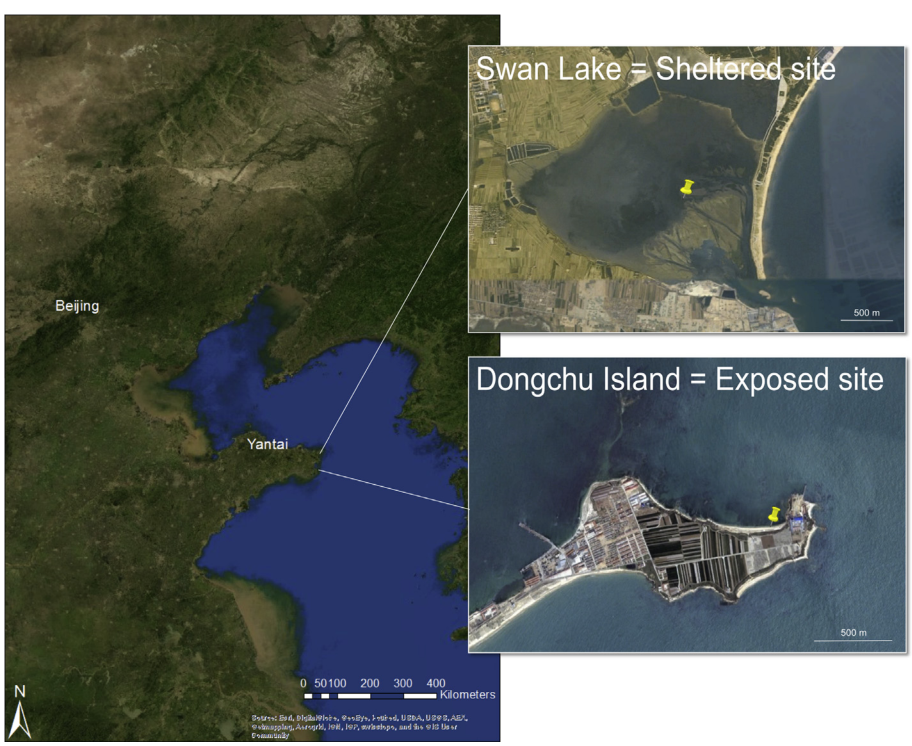

Fig. 1. Site localisation in the Shandong province.