D2.3: Mathematical model on the interactions between seagrasses and other engineering species

Marine Ecosystem Restoration in Changing European Seas MERCES

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Executive Summary

A mathematical model was developed describing the development of spatial seagrass patterns. An important goal here was to investigate whether the patterns and patches that one typically observes in seagrass beds would reveal how seagrass beds are expected to develop, and hence whether they could form the basis for an indicator system for forecasting seagrass restoration success. The model is capable of describing the patterns that are observed in real-world seagrass beds, focusing on the statistical properties of the seagrass patches that can be observed in existing seagrass beds. Two important conclusions were drawn from the models. First, given the dynamic nature of seagrass patterns, restoration efforts that aim to repair patches or small beds that were lost to human disturbance may face limited success, as small emerging patches are always at a disadvantage (conform observations: Suykerbuyk et al 2016, J. of Appl. Ecol. 53 pp.774). It could be a better approach to facilitate the growth or expansion of large, existing patches or beds. Second, the model revealed that the size distribution of the seagrass patches reveals to what extent the seagrass bed occurs in conditions that allow for bed persistence, or whether the patches are expected to disappear in the future. Due to limited success of seagrass restoration early in the project, we were unable to extensively validate the model's predictions. Following sufficient validation of the model and the indicator system that is derived from it, the model could provide important insights in the chances of long-term success of seagrass beds following successful establishment.

1. Introduction

The NIOZ has performed a mathematical modelling study on the spatial development of seagrass patterns. An important goal here was to investigate whether the patterns and patches that one typically observes in seagrass beds would reveal how seagrass beds are expected to develop, and hence whether they could form the basis for an indicator system for forecasting seagrass restoration success. The study outlines a new modelling framework that describes the dynamics of seagrass beds under sediment or nutrient limitation, and includes the effect of grazing. The model is capable of describing the patterns that are observed in real-world seagrass beds, focusing on the statistical properties of the seagrass patches that can be observed in existing seagrass beds.

2. Seagrass pattern formation

Seagrass beds are only rarely homogeneous. In intertidal flats, seagrasses typically build muddy hummocks on more sandy substrate, as their leaves stimulate the capture of sediment. Draining water and grazing by geese can keep the areas in between the patches open. In subtidal areas, seagrass can form sediment ridges in apparent interaction with water flow. We developed a set of models that captures pattern formation in seagrass beds, especially those driven by nutrient or sediment accumulation, including the effects of grazing. These models do not capture every possible mechanism of seagrass pattern formation, but take into account the three most important ones (nutrients, sediment, grazing).

With these models, we investigated how seagrass patchiness would develop. Different from other pattern-forming systems (for instance mussel beds, and arid desert vegetation), seagrass patterns were predicted to be continuously changing, as the patches were in apparent competition for nutrients and sediment. As a result, patches were predicted to get bigger and bigger, even when cover is stable, unless disturbances would fragment them again.

Fig. 1: Output of a spatial model of seagrass patches, and patches in a real-world Zostera noltii seagrass bed in the Eastern Scheldt.

3. From mathematical model to an aid in seagrass restoration

Two important conclusions were drawn from the models. First, given the dynamic nature of seagrass patterns, restoration efforts that aim to repair patches or small beds that were lost to human disturbance may face limited success, as small emerging patches are always at a disadvantage (conform observations: Suykerbuyk et al 2016, J. of Appl. Ecol. 53 pp.774). It could be a better approach to facilitate the growth or expansion of large, existing patches or beds. Second, the model revealed that the size distribution of the seagrass patches reveals to what extent the seagrass bed occurs in conditions that allow for bed persistence, or whether the patches are expected to disappear in the future. When the distribution is skewed towards smaller patches, the bed is likely to be healthier, as the small patches are the most vulnerable element. A size distribution that is more skewed towards larger patches, having lost the more vulnerable small patches, is likely to be less healthy. We emphasize that this does not deal with the absolute size of the patches, but about the size of patches relative to each other (i.e. the average patch size).

The model predictions are likely to be robust for seagrass beds governed by sediment of nutrient as growth-limiting resource and can even be valid for beds governed by grazers, provided that the estuary-wide stock of nutrients, sediment and grazers is relatively constant. This is a rather abstract restriction, but in many estuarine systems, sediment and/or nutrient amounts are relatively fixed, at least a short timescales, meaning that the model provides a reasonably good description of the general dynamics of seagrass beds when there is no excessive human-induced sediment loading or eutrophication. Furthermore, a treatment of water flow, which was excluded from the current project, could further improve the realism of the predicted patterns, and most interestingly, would allow the treatment of the effects of pattern formation on drainage efficiency. This, however, was beyond the scope of the project.

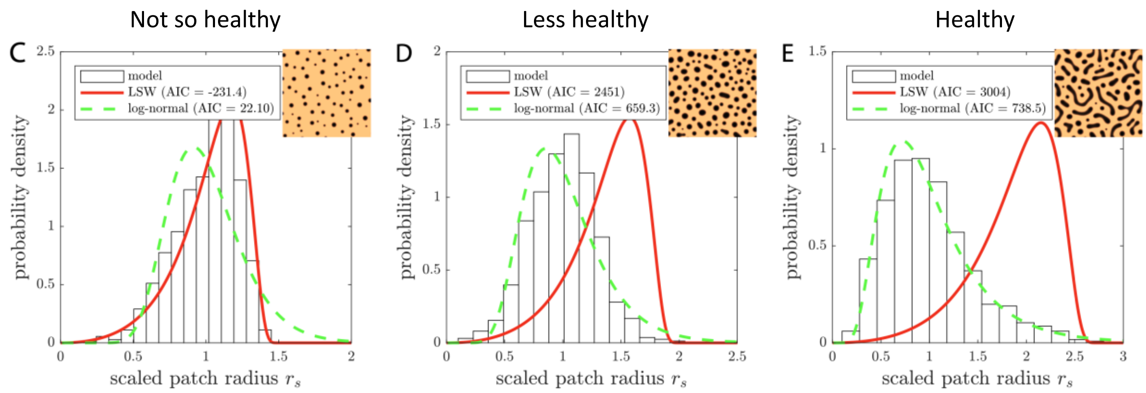

Fig. 2: Patch size distributions can reveal whether a seagrass bed is growing under more or less heathy conditions. For explanation we refer to the paper.

4. Limitations

Within the MERCES project, validation of model predictions were hampered by the (initially) limited success of seagrass restoration efforts. Hence, the model predictions could not be validated with the data obtained from the project. In the MERCES project's final year (with the 2-year modelling study completed), *Zostera marina* was successfully restored at large scale in the Wadden Sea with new seed injection methods. A follow up restoration project could further develop and validate the model's predictions here.

The model outlines that management practices dealing with seagrass establishment and seagrass bed dynamics should focus on managing seagrass beds at large spatial scales, as seagrass patches are locally very vulnerable, but will have a tendency to maintain large-scale cover provided that conditions for growth are sufficient. We have provided indicators that can help distinguish whether seagrass beds are – on the large scale – living in conditions that allow long-term persistence, or whether they are intrinsically vulnerable to decline.

The results will be presented in the following paper:

Koen Siteur, Quan-Xing Liu, Vivi Rotschäfer, Max Rietkerk, Arjen Doelman, Maarten Eppinga, Nigel Goldenfeld, Tjisse van der Heide, Christoffer Boström, and Johan van de Koppel. Phase-separation physics underlies new theory for the resilience of patchy ecosystems. In preparation for PNAS (preliminary author list).

5. Outreach

The NIOZ has produced two movies and a website that have the goal to disseminate the results of our modelling work (movie 1) and the use of BESE to protect foreland ecosystems (movie 2, partial contribution) to professionals and the general public. See below an 3D visualization image outlining how a mussel bed, by protecting a seagrass bed in its wake, helps improving coastal safety.

Video: Modelling the dynamics of seagrass beds.

https://youtu.be/eR597hBxHVQ

Video: The importance of ecosystem-engineers in protecting coastlines

https://youtu.be/ApfY0dWTL6E

A very recent development in our outreach and public-outreach is the use of 3D panoramic imagery to provide an immersive explanation A closer look can be taken using this link, that reveals the above landscape using virtual reality techniques.

https://dataportal.nioz.nl/visualmodels/BESE/

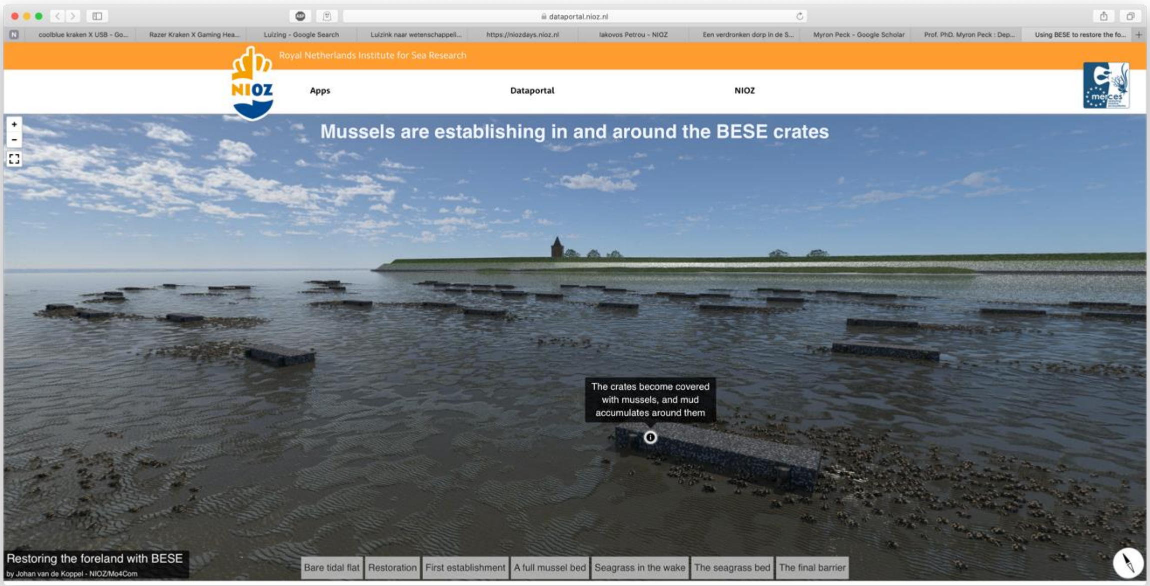

Fig.3. Picture from the Online-VR system.

Overview of paper:

Papers:

Koen Siteur, Quan-Xing Liu, Vivi Rotschäfer, Max Rietkerk, Arjen Doelman, Maarten Eppinga, Nigel Goldenfeld, Tjisse van der Heide, Christoffer Boström, and Johan van de Koppel. Phase-separation physics underlies new theory for the resilience of patchy ecosystems. In preparation for PNAS (preliminary author list).

Side papers, involving MERCES PostDoc Koen Siteur:

Reijers, V. C., Siteur, K., Hoeks, S., van Belzen, J., Borst, A. C., Heusinkveld, J. H., Govers, L.L., Bouma, T.J., Lamers, L.P.M., Van de Koppel, J. & van der Heide, T. (2019). A Lévy expansion strategy optimizes early dune building by beach grasses. Nature communications, 10(1), 1-9.

Li-Xia Zhao, Quan-Xing Liu, Koen Siteur, Xiu-Zhen Li, Johan van de Koppel . Fairy circles imply high resilience of self-organized salt marshes. Science Advances, Science Advances, accepted.

6. References

Suykerbuyk, W., Govers, L. L., Bouma, T. J., Giesen, W. B., de Jong, D. J., van de Voort, R., ... & van Katwijk, M. M. (2016). Unpredictability in seagrass restoration: analysing the role of positive feedback and environmental stress on Z ostera noltii transplants. Journal of Applied Ecology, 53(3), 774-784.