Investigation of Pattern Formation in Marine Environments Through Mathematical Modeling and Analysis of Remotely Sensed Data

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Abstract

Pattern formation in ecological systems refers to a nonuniform distribution of animal or plant species across a landscape. Pattern formation can be observed in many aquatic and terrestrial systems and can provide important insights into their dynamics and ability to cope with environmental and anthropogenic changes. In this dissertation, we focus on pattern formation in tidal marshes and oyster reefs, two important habitats that provide a number of essential ecosystem services. Both of these systems have also experienced dramatic losses, prompting much research to investigate their dynamics and viable restoration and management strategies.

The first part of this dissertation focuses on understanding the spatial patterning of the marsh shoreline, which can range from a uniform to a more wave-like shoreline. We present a mathematical framework for modeling the spatial variation of the shoreline as a result of interactions between marsh vegetation and mussels and their impact on marsh sedimentation and erosion. While both species are known to significantly impact marsh dynamics, no mathematical model describing this phenomenon has been previously proposed. Numerical and analytical investigation of our model indicates that the interactions between these species can drive the spatial variation of the marsh edge, increase the system's productivity and allow it to withstand harsh erosion conditions.

The second part of this dissertation focuses on pattern formation in intertidal oyster reef communities, where both round and elongated reefs of various orientations dominate the landscape. Most of what is currently known about reef geometry has been anecdotal, with no comprehensive, quantitative study of reef pattern formation carried out. In particular, the interaction of oyster reefs of various geometric configuration with tidal flow remains poorly understood. This is important in reef restoration, where understanding the interaction of reef geometry with flow and other environmental factors can inform the construction of artificial oyster reefs. In this dissertation, we present a comprehensive analysis of remotely sensed aerial imagery of an intertidal oyster reef network in conjunction with information on tidal flow dynamics and bathymetry. Using texture and color properties of the aerial imagery, we identify and delineate over six thousand individual reefs. We then classify reefs into natural classes based on geometric attributes such as reef shape, size and orientation. Finally, we use multiple spatial analysis techniques to determine the spatial clustering of different reef types and investigate the role of flow and bathymetry in their spatial distribution.