Integrated Monitoring and Eco-Morphodynamic Modeling of Coastal Dunes

Abstract

Coastal dunes are extremely dynamic ecotones where marine and land processes merge together.

They provide essential ecosystem services, including biodiversity conservation, natural protection against coastal hazards, and support for local economies. Despite their importance, dune systems worldwide are increasingly threatened by climate change, shoreline erosion, invasive species, and human pressures, leading to degradation of their protective and ecological functions.

Effective management and restoration of coastal dunes therefore require improved understanding of the co-evolution of biotic and abiotic dynamics across multiple spatial and temporal scales.

This PhD thesis develops a fine-scale integrated monitoring and predictive framework for coastal dunes, with a particular emphasis on vegetation as a key indicator and driver of dune dynamics.\\

The research addresses critical gaps in long-term monitoring and in the integration of geomatics-derived observations with physically based hydrodynamic and eco-morphodynamic models, with the sandy dunes on the coast of Migliarino–San Rossore–Massaciuccoli Regional Park serving as a test bed.

The first part of the thesis focuses on the monitoring phase, evaluating the feasibility and effort required to construct an integrated, multi-temporal dataset combining airborne observations (e.g. RGB and multispectral optical imagery, LiDAR point clouds), ground-based measurements (e.g. vegetation surveys and ground control points), and marine data (e.g. multibeam-derived bathymetric point clouds).

The processing and analysis of these heterogeneous datasets provide a quantitative and qualitative assessment of coastal dune dynamics, allowing the investigation of the mutual interactions among geomorphology, hydrodynamics, and vegetation in controlling coastal dune evolution.

Finally, the work converges on the formulation of a predictive eco-morphodynamical model, addressing the specific task of estimating the post-storm recovery time of dunal vegetation, a process that remains poorly understood and insufficiently explored in the scientific literature.

While the proposed model is still in its infancy and remains to be fully explored and generalized, it lays the groundwork for future developments and has the potential to significantly support more effective coastal dune restoration and conservation strategies.