Contribution ID: **66** Type: **Short Talk**

Exploring the Potential of Graph Neural Networks to Predict the State of Seagrass Ecosystems in Italian Seas

Thursday, 3 October 2024 12:10 (10 minutes)

Marine and coastal ecosystems (MCEs) play a vital role in human well-being, contributing significantly to Earth's climate regulation and providing ecosystem services like carbon sequestration and coastal protection against sea level rise. However, they face serious threats, including one deriving from the interaction between multiple human stressors (e.g. pollution) and pressures more related to climate change (CC) (e.g. rising sea temperature, ocean acidification, etc.). The complex interplay of these pressures is escalating cumulative impacts on MCEs, jeopardizing their ability to provide ecosystem services and compromising their health and resilience. Machine Learning (ML), using different types of algorithms such as Random Forest (RF) or Support Vector Machine (SVM), can be effective tools to evaluate changes in environmental and ecological status against multiple pressures, but they often overlook the spatial dependence of pressure effects. The examination of spatial relationships among anthropogenic and CC-related pressures is facilitated by Graph Neural Networks (GNNs), which explicitly model the relationships between data points, hence offer potential solutions to the issue of neglecting spatial dependencies in the prediction. Based on these considerations, the main aims of this study are exploring the application of GNNs-based models to evaluate the impact of pressures on Seagrasses ecosystem in the Italian Seas and compare these methods with the models that usually are employed in this field (i.e., RF, SVM, Multi-Layer Perceptron (MLP)).The methodology involves compiling a comprehensive dataset encompassing key variables influencing Seagrass health, including several endogenic and exogenic pressures (e.g., nutrient concentrations, temperature, salinity). Geospatial data from open-source platforms (e.g., Copernicus, EMODnet) are processed and synthesized into a 4km raster grid. The study area was defined based on 2017 seagrass coverage, considering a bathymetry layer up to 50 meters. The seagrasses distribution in each pixel of the case study was considered, categorizing the latter as presence or absence pixels. Experiments include implementing and evaluating different GNN architectures, (i.e., Graph Convolutional Networks (GCNs) and Graph Attention Networks (GATs)), alongside traditional ML models. To construct the graph for GNNs, each pixel in the study area, identified by latitude and longitude, is a node. The feature vectors associated with each node represent the pressures. Nodes are connected to their nearest neighboring pixels, forming a spatially informed graph structure. Model performance is assessed using accuracy and F1-score metrics, with GNNs showing the highest F1-score in detecting presence of seagrasses. Qualitative analysis reveals that models lacking spatial context in their predictions tend to exhibit errors attributed to isolated consideration of individual pixels. For instance, these models incorrectly predict the absence of seagrass in regions surrounded by meadows or vice versa. In contrast, GNNs predominantly misclassify pixels along seagrass patch boundaries. While spatial context proves invaluable for prediction accuracy, challenges stemming from limited data availability of high-resolution datasets, impede comprehensive exploration of temporal dynamics within seagrass ecosystem. Future research aims to transition to a local scale, gathering high-resolution data. This facilitates the incorporation of temporal dimensions and the consideration of relevant physical processes, such as ocean currents or extreme events, influencing ecosystem dynamics within the graph.

Topic

Environmental informatics: Climate Change/Environment

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Session Classification: Processing Research Data with Artificial Intelligence and Machine Learning