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DOCTORAL DISSERTATION ABSTRACT

Scientific discipline: **biological sciences**

Title of the doctoral dissertation: **Goal functions and the assessment of natural capital and ecosystem services**……

Doctoral dissertation abstract:

The Earth System is nowadays facing an unprecedented crisis due to intensifying anthropogenic pressures that are leading to an ecological deficit. By extracting resources at a rate exceeding their natural regeneration and emitting waste beyond ecological carrying capacities, humans are destabilizing the biosphere. Therefore, in a world increasingly impacted by human activities, understanding ecosystem functioning and the condition of Natural Capital stocks is crucial for ensuring human well-being.

Multiple theories and methodological approaches have been proposed for assessing and valuing nature and its services. Among them, notable are the Goal Functions, which can be conceptualized as propensities towards which ecosystem evolution is oriented, providing information about ecosystems, their configurations, and functions over time. GFs may be grouped into three main categories: biotic, network, and thermodynamic. In particular, thermodynamic Goal Functions base their concept on the laws of thermodynamics and the entropy principle, accounting for matter and energy within ecosystems to evaluate the intrinsic worth of natural systems, enabling a comprehensive understanding of their complex dynamics.

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The attribution of biophysical and economic value to the benefits ecosystems offer is indispensable. In this regard, the United Nations established the System of Environmental Economic Accounting-Ecosystem Accounting (SEEA-EA) framework, which provides a standardized approach for accounting ecosystem service flows in both biophysical and economic terms, aiming to incorporate their value into decision-making processes.

Within this context, the goal of this doctoral thesis was to apply a biophysical approach to explore the exchange of matter and energy flows in the functioning of ecosystems, with a particular focus on the assessment of natural capital and ecosystem services.

To explore natural capital values, ecological complexity, and efficiency in ecosystems, we investigated three different types of lakes located in the Tuchola Forest UNESCO-MAB Biosphere Reserve (Northern Poland). By jointly applying emergy and eco-exergy Goal Functions, we tested the hypothesis that lakes of different trophies (e.i., oligotrophic, mesotrophic, and eutrophic) differ regarding natural capital value, system complexity and functioning. Moreover, using the eco-exergy / emergy ratio, we assessed the efficiency of the investigated ecosystems, describing the role of matter and energy flows in maintaining the structure of lake ecosystems over time. Our findings revealed that eutrophic lakes showed the highest natural capital measured in terms of emergy and eco-exergy values. However, the mesotrophic and oligotrophic lakes displayed a higher efficiency in maintaining and developing ecosystem structures and organizations.

The second hypothesis assumed that Natural Capital stocks can be affected by environmental parameters and anthropogenic pressures, and their changes can be detected by thermodynamical goal functions. Testing this hypothesis, we studied marine human-affected ecosystems of the Mediterranean Sea, in particular the Strait of Sicily (Italy). By applying the eco-exergy method, we assessed the complexity and dynamic of natural capital stocks over time. Moreover, spatial and hotspot analysis of eco-exergy and diversity indices were performed to identify key areas crucial for conservation strategies and marine spatial planning. Results showed a decline of natural capital stocks over time, correlated to environmental parameters including temperature and pH. In addition, changes in the structure and complexity of the ecosystems were found. Furthermore, by combining eco-exergy and the Shannon index, two important areas were identified for conservation purposes.

The third hypothesis stated that variation in ecosystem services supply can be caused not only by human activities but also by intense natural disasters. We tested this hypothesis using the SEEA-EA framework, assessing the ecosystem assets and then ecosystem services provided by the forests of Tuchola Forest UNESCO-MAB Biosphere Reserve (Poland). In particular, the ability of the forests to remove air pollutants (PM10, PM2.5, NO2, and O3) and the loss of function caused by a hurricane were assessed. Findings showed the structure and composition of the forest (mainly covered by conifers and broadleaf functional groups) and its ability to highly contribute to air quality amelioration. Overall, removal efficiency revealed variations depending on the vegetation period of trees, phenological and physiological parameters, and the pollutant concentration. The total economic value of the regulating ecosystem services of air pollution removal was estimated in 791 million euros per year. Furthermore, changes in ecosystem services supply due to natural disasters highlighted how

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climate change and related extreme events can compromise the provision of benefits to humanity, with a loss of 7.4 million euros.

The research conducted within this doctoral study has demonstrated that ecological Goal Functions serve as a valuable tool for assessing natural capital, ecological complexity, and ecosystem dynamics. Furthermore, the evaluation of ecosystem services has emphasized the importance of attributing both biophysical and economic value to ecosystem goods and services in order to integrate their worth into decision-making processes, thereby preserving human well-being.

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doctoral student's signature