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Bioeconomic analogies as a unifying paradigm for modeling agricultural systems under global change in the context of geographic information systems

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Global change in agro-technical inputs, invasive species, and climate change disrupts and increases the time-varying complexity of the ecological roots of agricultural and natural systems. These systems are inherently complex as each of the interacting species of plants, animals and diseases have unique requirements for growth, survival, and reproduction in response to weather and abiotic factors that determine their geographic distribution, abundance, and interactions. Global change affects each species directly (e.g., climate favorability) and indirectly by altering biotic interactions with other species (e.g., predation, parasitism, competition for food). Determining the direction and magnitude of changes in agricultural and natural systems caused by global change is a major challenge for developing sustainable management solutions, and requires deconstructing system complexity by separating the core ecological issues from climatic and impinging economic components. However, deconstructing and analyzing the complex tripartite ecological, economic, and social effects of global change is largely unexplored, and is a major constraint to achieving sustainability.

A bioeconomic approach using physiologically-based demographic models (PBDMs) in the context of a geographic information system (GIS) is an important step in examining the complexity of agricultural systems under global change. PBDMs are mechanistic descriptions (i.e. models) of the field biology, and are based on the unifying paradigm that all organisms including humans acquire and allocate resources by analogous processes (the paradigm of ecological analogies, see http://www.casasglobal.org/). PBDMs are built around the notion that analogous weather-driven sub-models for resource acquisition and birth-death dynamics can be used to predict explicitly the biology and dynamics of heterotherm species across trophic levels, including the economic level. PBDMs may include bottom-up effects of plant growth and development on herbivore dynamics, and the top-down action of natural enemies. PBDMs predict the weather-driven phenology, age structure and abundance dynamics, and the distribution of the interacting species across wide geographic areas using weather data from various sources including satellite remote sensing (RS) and climate change projections. The open source GIS software GRASS (http://grass.osgeo.org/) has been used to perform geospatial analysis and mapping of results. A number of factors affecting species distribution and abundance may also be integrated into PBDMs as digital data layers using GIS (see the Copernicus program https://www.copernicus.eu/). Realistic PBDMs can be used as the production function in bioeconomic analyses in agriculture at various spatial scales, and levels of renewable resource exploitation.

In summary, physiological, ecological, and economic analogies in PBDMs bring realism that help bridge the gap between bottom-up (primarily physiological and population dynamics) and top-down (climatological) GIS approaches for assessing critical/emerging ecosystem problems linked to global change such as agricultural pests, invasive species, and vector-borne diseases. The bioeconomic analogies of PBDMs provide a sound basis for developing a modeling platform with high level of generalization and abstraction. This platform would make the PBDM/GIS methods widely accessible with minimal expertise and infrastructure requirements, and would have immense long-lasting potential for helping solve critical environmental, agricultural, and health problems globally.