1) Proposed Research Focus:	Complex interactions among forest ecosystems, economies, and rural communities: Interdisciplinary research to enhance system resilience

2) Primary Contact Person:

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3) Suggested/Potential Key Senior Personnel:

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4) Intellectual Merit: (the research focus)

A. Need: Maine is one of the states most dependent on the effective and sustainable management of its forest resources. The forest products sector annually contributes $8 billion to the state's economy, which accounts for over 5% of the GDP (one of the highest in the US). However, the social-ecological systems (SES) that determine the health and value of these resources now face an uncertain future from changes in land use patterns, ownership and management objectives, market demand, disturbances and other ecological processes, and climate. Recently, Maine was declared a Federal economic disaster zone due to the closure of five pulp mills and reduced capacity at other production facilities throughout the state. Consequently, a new direction is needed, and addressing the current uncertainty requires a comprehensive research program that would examine and strengthen rural community resilience by focusing on understanding ecosystem service values, promoting individual and community health, and fostering diversified and robust forest-based economies. We conceptualize resilience as the ability of a system to absorb and effectively respond to change and we intend to address resilience through two lenses, by looking retrospectively and prospectively. First, we seek to understand how rural communities are currently responding to and recovering from the current economic crisis. Second, through the development and use of innovative approaches to research as well as Science, Technology, Engineering, and Math (STEM) engagement, we intend to build capacities to detect past and future SES change, harness new and diversified economic opportunities, and build the socio-technical infrastructure to spur further innovation in forest-based economies.

Traditionally, forest ecosystems and associated rural communities have been assessed using spatially and temporally coarse metrics. Furthermore, the metrics generally focus on a limited number of ecosystem and community attributes with a primary focus on existing commodity value and current economic production, while additional ecosystem services, alternative markets, and future uncertainty are generally not considered. Although difficult, there is growing societal interest and even financial demand for quantifying and forecasting the value of the other services provided by forest ecosystems in ways that define potential implications for and support the development of rural community resilience. For example, certified forest carbon currently has a market value of $13.55 per ton of CO_2 equivalent, and this value is

expected to increase, which translates to a carbon value in Maine of nearly $15 billion. In addition to carbon, other key ecosystem services include biodiversity, fiber, cultural, recreational, and air & water quality values, which all require more extensive monitoring and metrics than currently available. Using participatory modeling approaches, including scenario development, causal loop diagrams, and systems dynamics simulations, we will bring together scientists, forest products stakeholders, regulators, and policy makers to define and model SES interactions. Through participatory modeling, collaborators will identify data-driven policy interventions and economic and community development schemes to build and sustain rural community resilience.

In addition, dramatic changes over the last decade in available technology, computational power, analytical methods, and coupled SES have occurred. These include key technologies like automated measurement instruments and wireless sensors, digital imagery from manned and unmanned airborne and spaceborne platforms, and 3D laser profiling scanners. Key analytical shifts have grown from greater utilization of machine learning and other sophisticated algorithms capable of detecting and predicting patterns in massive datasets. Despite these changes, limited utilization of these newer technologies, analytical methods, and coupled SES frameworks has occurred in Maine. This is primarily because of the significant investments needed in physical, human, and cyber infrastructure.

B. Research Goal & Objectives: The goal of this project is to advance research in ways that will build rural forest-based communities and economies that are able to detect, withstand, and recover from current and future change. The primary project themes are: (1) Technology Development and Implementation; (2) SES and Economic Informatics and Analytics; and (3) SES Participatory Modeling. In addition to these themes, significant project efforts will focus on involving key stakeholders and educating and training individuals on the developed technology, informatics, analytics, and linked SES frameworks to quantify ecosystem services and community resilience for better informed decision-making.

C. Research Actions: This project requires a comprehensive, integrated, trans-disciplinary, and statewide effort across multiple institutions. In particular, the project will involve expertise in forestry, landscape ecology, remote sensing, statistics, economics, communication, computer science, engineering, spatial information, wildlife, hydrology, data informatics, and business across a number of institutions including University of Maine, University of Southern Maine, University of Maine Fort Kent, University of Maine Presque Isle as well as several industry/community partners like forest landowners (e.g. JD Irving, Seven Islands, Weyerhaeuser), geospatial technology companies (e.g. Sewall, Blue Marble, Quantum Spatial), state agencies (e.g. Maine Forest Service, Maine Office of GIS) and nonprofit organizations (e.g. Maine Development Foundation, The Nature Conservancy). Using the developed technology, a statewide socio-ecological observational network would be implemented for assessing biodiversity, carbon, cultural, fiber, water values, and community resilience at relevant spatial and temporal scales. Socio-ecological and economic informatics and analytics would then be paired with participatory modeling involving key stakeholders to identify past trends and predict potential future outcomes under a range of alternative scenarios for each of the key ecosystem services and community metrics. To ensure sustainability and accessibility, computational and SES models would be developed and utilized for providing a state of the art online user computer interface to the data and generated products. This would reduce informational barriers that currently exist and provide STEM education and training for individuals with diverse backgrounds. Specific research questions to be addressed are: (1) What are the key driving factors for current and future ecosystem service and community resilience; (2) What are the greatest sources of future uncertainty influencing potential value and resilience; and (3) How does increased quantification of the resource and human interactions with it improve understanding and management of future conditions?

D. Priority: This effort would address many key priorities across a broad array of NSF programs including Bio., Comp. & Info. Sci. & Eng., Cyberinfrastructure, Eng., Env. Res. & Ed., Geosci., Math & Phys. Sci., and Soc., Beh., & Eco. Sci..

5) Broader Impacts: (related to the research focus)

E. Societal Impacts*:* Forest ecosystems provide a broad range of societal benefits including biodiversity, carbon, cultural, fiber, recreation, and water. Valuation of these ecosystem services would ensure their

	sustainable management with key implications for rural community resilience, which is critical given the array of factors influencing their future uncertainty. In particular, the methods would help to support the important values that forest ecosystems provide to Maine's citizens, most notably key connections made to tribal communities provided by Co-PI Darren Ranco (a member of the Penobscot Nation).
F.	***Economic Impacts**:* Maine is highly dependent on the health and sustainable management of its forest ecosystems. Given the uncertain future of the current forest economy, a new direction is needed. The technology, information, analytical methods, and coupled systems provided by this project would significantly improve management as well as provide valuation of other key ecosystem services beyond fiber. There is significant and growing capital interest in these ecosystem services, which could create new and substantial markets for Maine's extensive natural resources. However, technology, and informatics are needed to attract these new capital investments and support cost-efficient and effective decisions on how to best utilize these resources.
G.	***Workforce Development Impacts**:* A workforce that understands new technology and data science as well as ecosystem management are in strong demand, particularly in a state economy heavily dependent on sustainable natural resource management like Maine. This project would provide a broad array of STEM opportunities for undergraduates, graduate, post-doctoral, faculty, and professional workforce. Currently, there is limited and poorly integrated statewide training opportunities for geospatial technologies, remote sensing, data science, and coupled SES in Maine. In addition to these skills, individuals would be trained in a multi-disciplinary and applied fashion with a broader understanding of complex and interactive SES.
H.	***Infrastructure Impacts**:* Technology, cyberinfrastructure, data science, and SES models are the future. This project would require significant investment and development of key human, physical, and cyber infrastructure in an array of key focal areas. In particular, there is currently limited human infrastructure in the state focused on informatics and analytics, which is now considered one of the fastest growing professions.