# Near-term Ecological Forecasting

This memo provides a briefing on, and recommendations for, an ecological forecasting research initiative to support actionable public and private decisions (e.g. natural resource management, national security, and climate adaptation and mitigation) while advancing our fundamental scientific understanding about the predictability of the Earth system.

Ecological Forecasting Initiative
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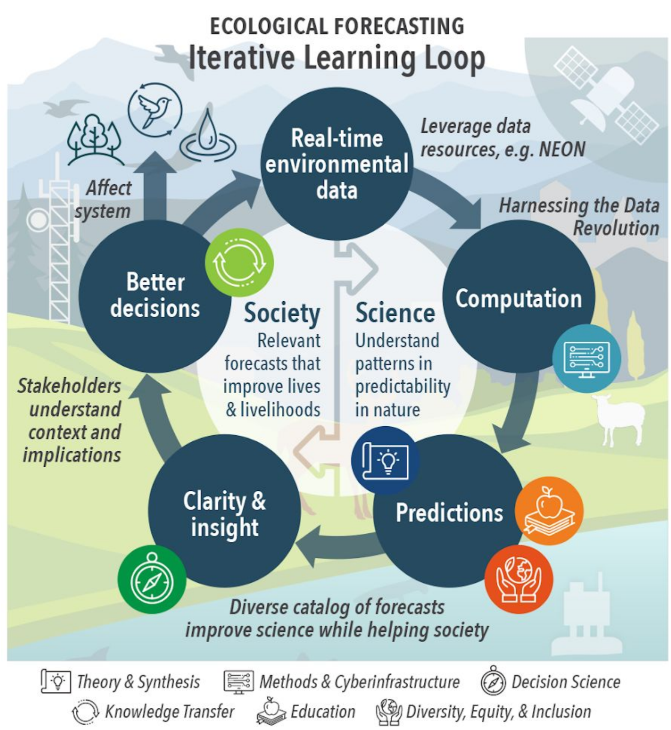
## KEY POINTS

1. In our time of rapid environmental change, there is an urgent need for **ecological forecasts: continually-updated, actionable predictions of the future state of ecosystems, their services (e.g. water quality, forest products, fisheries, carbon sequestration), and risks (e.g. infectious disease, invasive pests) that improve environmental decision making, management, and conservation**.
2. Meeting this need is achievable, but requires increased Federal investments in both forecast research and operations, sustained investment in observational and satellite monitoring, and clear mandates to Federal agencies to operationalize actionable ecological forecasts.
3. An interagency Ecological Forecasting Research Initiative is needed to tackle grand challenge scientific questions about ecological and Earth system predictability, coordinate training, research, and forecasting activities, and provide economies of scale around technology development. Such an effort should include activities that engage academic, NGO, and private sector experts and users to prioritize and advance the field.

## WHY ECOLOGICAL FORECASTING?




**Widespread environmental change is the defining challenge of our time**, with impacts already being felt across all levels of society (e.g. global change, disease, loss of biodiversity). Rather than a 'new normal,' we are facing continuous, accelerating, and at times non-linear change, as demonstrated by unprecedented floods, wildfires, coral bleaching, and extinction events. Because of this change, our nation can no longer rely on past patterns (e.g. 100-yr flood, historical species ranges) for environmental decision-making – we are in uncharted territory. **Our ability to understand nature, manage and conserve natural resources, predict outbreaks of new diseases and**

**invasive species, and sustain economic growth in the 21st century urgently requires a capacity to anticipate environmental change at a scale and speed far beyond what is currently possible.**

**Near-term (daily to interannual) ecological forecasts meet this critical need by providing continually-updated, actionable predictions of the future state of ecosystems and their services (Dietze et al. 2018)**. These near-term forecasts allow society to anticipate challenges on decision-relevant timescales, adapt to change, and improve decision making for everyone from individual citizens to nations. For example, daily forecast maps of endangered fish and other bycatch are being used by fishers to optimize their fishing effort to avoid bycatch. Daily forecasts of reservoir water quality, algae, and methane emissions are being used to reduce costs, improve drinking water, and enhance carbon sequestration. Other examples of **current ecological forecasts with direct links to ongoing resource management decisions include**: wildfire risk; zoonotic diseases (e.g. ticks, mosquitos); crop, forest, and rangeland yield, drought stress, and carbon sequestration; harmful algal blooms; movements of birds, bats, fish and large-mammals; rangeland restoration; and population trends for managed wildlife, invasive species, and threatened/endangered species. Many ecological forecasts also include explicit projections under **alternative management scenarios**.

**The need for ecological forecasting cuts across all of society**. Improved forecasts of natural and managed ecosystems (e.g. farming, ranching, forestry, fisheries, reservoirs) will enhance national security, economic vitality, and environmental quality. Ecological forecasts have a demonstrated potential to enhance operations across the federal government, including the CDC (e.g. One Health, zoonotic disease), and the Departments of Defense (e.g. biosecurity), Agriculture (e.g. drought, grazing, wildfire), and Interior (e.g. wildlife, water management) (Bradford et al 2020). Similar applications of ecological forecasts can improve resource management decisions at Tribal, state and local levels. **Ecological forecasting applies 21st century science to increase the effectiveness and efficiency of 21st century environmental management** (Bradford et al 2020) **and is a critical centerpiece in a broader need to improve Earth system predictability** (OSTP 2020).

## WHAT IS NEEDED?

### 1. Sustained Federal investments in monitoring and computation.

Meeting the need for ecological forecasts is not only urgent, but it is timely and achievable. The capacity to forecast is fueled by recent advances in sensor technologies, Earth system science modeling, satellite-based observation systems, genomic tools, high-performance computing, community science initiatives, and shifts toward large-scale networked science that now provide access to previously unimaginable volumes of near real-time environmental data. At the center of this data revolution have been **sustained Federal monitoring investments** in satellite earth observations (NASA, NOAA, USGS), network and observatory science (e.g. NSF's National Ecological Observatory Network, LTER, CZO; USDA's LTAR), and field monitoring by a wide range of Federal agencies (USGS, DOD, USDA, USFS, USFWS, NOAA, EPA, CDC, etc). Similarly, **sustained Federal computational investments** in synthesis and modeling (e.g., NSF, DOE, NASA, NOAA, NCAR), computational capacity, data management and delivery, and advances in artificial intelligence and machine learning underpin our ability to rapidly improve ecological forecasts.

**2. Funding for forecast Research and Training**

Decades of progress in weather forecasting demonstrates that increasingly reliable predictions are possible for complex natural systems if we adopt iterative approaches. By continually updating forecasts through the assimilation of new data, we can accelerate the pace of learning, model improvement, hypothesis testing and scientific inference. Putting this into practice in ecological forecasting requires advancements in **theory, technology, and training (3T)**.

- **Theory**: For ecology to become a more predictive science, we need a better theoretical understanding of **what makes natural systems predictable.** Researchers are working to understand the 'Rules of Life' that enable ecological prediction in ways that generalize beyond individual systems. A new era of ecological forecasting will need to address this **scientific grand challenge** through a synthetic understanding, across the world's natural and managed habitats, of the factors controlling the predictability of different ecological processes. This effort is an essential component of the broader mission to improve Earth system predictability (OSTP 2020).
- **Training and Workforce Development**: Technical training in computation, statistics, and forecasting is a significant barrier for most ecologists, but this can be addressed via inclusive recruitment, education, and training, spanning from undergraduate through professional training and extension. Best practices for enhancing diversity and inclusion can contribute to a diverse, results-oriented workforce. In addition, as demonstrated by the numerous *ad hoc* COVID forecasts produced by untrained individuals, there is a growing need for **professional certification** (and legal protections for certified forecasters) similar to weather forecasters.
- **Technology**: Current forecast workflows are largely independent, system-specific solutions that require significant technical knowledge to engineer and are costly to set up and maintain. An investment in FAIR **community cyberinfrastructure** (Fer et al. 2020) will provide a massive economy of scale by openly developing and deploying accessible, reusable, and scalable cyberinfrastructure and statistical tools that can be broadly applied to produce large numbers of ecological forecasts. This will in turn accelerate Theory and Training.

Currently there is insufficient funding to meet the urgent need to **grow and sustain the fundamental research and development** that underpin ecological forecasts. Within and across Agencies, there is a need to dedicate funds toward a range of interdisciplinary adaptive management **partnerships between researchers and managers** that provide the needed advances in not just ecology, but also the **social and decision sciences** that translate predictions into practice.

**3. Mandate & funding to move from research to operations:**

Forecasts can only benefit our nation's security, economy, and environment if they are made and used. **Achieving this requires government Agencies, Tribes, industry, academics, NGOs, and other stakeholders to work and innovate together** to develop, improve, and operationalize forecasts. Some forecasts might be best generated by the **private sector** (e.g., precision agriculture), whereas other forecasts should be treated as **public goods**, the same as weather forecasts and health advisories. However, progress is being limited by **challenges in moving from research to operations**.

1. **Support pathways from research to operations for successful forecasts.** Agencies that support the basic and applied research to enable forecasts (e.g. NSF, NASA, USGS, NOAA, DOD, DOE) are often different from the organizations that produce and deliver forecasts (e.g., State and Federal Agencies, industry). There need to be clearer pathways to operationalization (e.g., programs that support R&D to identify and develop promising forecasts and then transition them to the appropriate Agency or private sector partner for operationalization).
2. **Give authority to agencies to operationalize data products and forecasts.** For example, NASA's Carbon Monitoring System has invested a decade of research into Monitoring, Reporting, and Verification technologies of direct relevance to international climate treaty requirements, but lacks the authority to provide these on a continual, reliable basis, which has hindered uptake by stakeholders. On top of this, Federal agencies need a **clear mandate that the production of ecological forecasts is within their mission**.
3. **Once forecasts are operational, provide funding to sustain them.** This includes support for maintenance costs, evidence-based decision support systems, and the communities of practice between researchers and practitioners that advance the use of forecasts.

## RECOMMENDATION: CREATE AN INTERAGENCY INITIATIVE

To address all of these challenges, we advocate for the creation of a **National Research Initiative on Ecological Forecasting**. An interagency initiative would provide and sustain the coordination and economies of scale that are currently lacking across the many Agencies and organizations now building ecological forecasting into their strategic priorities. Such an initiative would have two synergistic goals: 1) accelerate the production of a wide-range of societally useful forecasts; and 2) produce a deeper understanding of the limits of ecological predictability and how best to produce forecasts , with the aim of sharing this knowledge with interested parties. The latter goal prioritizes the Theory, Technology and Training (3T) described above, developing best practices in these areas, and creating a culture for the production and use of forecasts along the research to operations continuum. We suggest that both goals could be supported through an "incubator" model, where numerous experimental forecasts are produced and evaluated that "fail faster." This model would foster the development of shared tools, infrastructure, and expertise that would accelerate the production of forecasts. This would in turn allow us to better understand what systems are predictable and what approaches to prediction work best (e.g. machine learning vs. process-based models). An initiative would also allow a more coordinated approach to stakeholder engagement, technology transfer to and from the private sector, and the advances in the social and decision sciences needed to ensure that improved forecasts translate into improved decision making.

*This paper was prepared by the Ecological Forecasting Initiative, a grassroots research consortium working to build and support a community of practice around ecological forecasting.*
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## RECOMMENDED SOURCES

Dietze et al. 2018. Iterative near-term ecological forecasting: Needs, opportunities, and challenges. PNAS 115:1424–1432.

Bradford et al. 2020, Ecological forecasting—21st century science for 21st century management: U.S. Geological Survey Report 2020–1073, 54 p.,

Fer et al. 2020. A Roadmap to Community Cyberinfrastructure for Ecological Data-Model Integration. Global Change Biology

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