Annual Report for the NSF-sponsored Ecological Forecasting Initiative Research Coordination Network

January 4, 2025

This is a condensed and updated report from our annual report to the National Science Foundation in December 2024 reflecting activities and accomplishments from the fourth year of the Research Coordination Network funding (DEB-1926388).

The overarching goal of the project is to create a community of practice that builds capacity for ecological forecasting by leveraging NEON data products. Through meetings, working groups, and collaborative code development we aim to achieve the following objectives:

Objective 1. Define community standards and best practices for developing, sharing, and archiving forecasts and models

Objective 2. Increase the number and diversity of NEON-enabled forecasts by developing and hosting the NEON Ecological Forecasting Challenge

Objective 3. Create educational materials to empower scientists at all career stages to forecast using NEON data products

Objective 4. Support the creation of software to produce NEON-enabled forecasts at intensive and collaborative coding-focused workshops

Objective 5. Align forecast outputs and decision support with the needs of forecast users at mission-driven agencies to guide decision-making, and

Objective 6. Synthesize forecasts to examine how limits to forecastability vary across ecological systems and scales.

Major Activities

Ecological Forecasting Initiative Research Coordination Network (EFI-RCN) accomplished its goals through multiple means that included an in-person workshop, virtual working group meetings, collaborative software development, and sessions at society meetings.

Our first major activity during the fifth year of the EFI-RCN was running the NEON Ecological Forecasting Challenge, where teams are challenged to forecast NEON data before it is collected (www.neon4cast.org). The “Challenge” was created by volunteer efforts of the RCN where teams have designed the protocols, created the cyberinfrastructure to support the “Challenge”, created training materials, and evaluated the forecasts. We maintained the challenge for five different themes, each organized by a theme-specific design team. The five themes were aquatic oxygen/temperature, beetle community diversity, tick populations, terrestrial carbon fluxes, and canopy phenology. We published one manuscript and had one accepted directly related to forecasts generated through the Challenge: “Predicting Spring Phenology in Deciduous Broadleaf Forests: An Open Community Forecast Challenge” by Wheeler et al. was published in Agricultural and Forest Meteorology and “What can we learn from 100,000 freshwater forecasts? A synthesis from the NEON Ecological Forecasting Challenge” by Olsson et al. was submitted to Ecological Applications (pre-print is already available). Both of these manuscripts were led by early career scientists. Additionally, the NEON forecasting challenge was highlighted in two manuscripts published in 2024 (Meyer et al. 2024; Dietze et al. 2024) and one that was submitted (Record et al.).

We focused on growing the community of scientists creating forecasts using NEON data by providing two training workshops on ecological forecasting with NEON data that engaged over 45 individuals across career stages. The first was at the Ecological Forecasting Initiative meeting in Finland where we ran a 0.5-day workshop for the European Chapter of the Ecological Forecasting Initiative (16 participants). The second workshop was at the Ecological Society of America (ESA) 2024 meeting where we provided a tutorial on the Beetle theme in the NEON Forecasting Challenge (30 participants). The material for the ESA workshop was published on the NEON learning hub: https://www.neonscience.org/resources/learning-hub/tutorials/neon-beetle-forecasting. The material from the meeting in Finland was submitted for publication in the Journal of Open Science Education (Olsson et al.).

Overall, over the 5 years of the project, 198 teams have submitted 73,619 unique forecasts across the five themes. This is up from the 164 teams having submitted 57,386 unique forecasts through the 4th year of the project. In total these forecasts resulted in 5,199,956 pairs of forecasts and observations that have or will be directly evaluated using NEON data. The NEON Ecological Forecasting Challenge is a resounding success in advancing theory, technology, and training by providing a focal point for the community that leveraged open data. We are empowering the ecological forecasting community to lead the charge in accomplishing NEON’s forecasting mission.

Our second major activity was expanding beyond the NEON Challenge by helping partners of the RCN develop forecasting challenges for their projects. First, the EFI-USGS River Chlorophyll Forecasting Challenge was developed to engage the community in forecasting chlorophyll-a data at USGS-monitored river sites (https://projects.ecoforecast.org/usgsrc4cast-ci/). To date, 920 forecasts have been submitted to the EFI-USGS Challenge. Second, the NSF-funded Virginia Ecoforecast Reservoir Analysis (VERA) was launched in collaboration with the team from the newly launched Virginia Reservoirs LTREB (DEB-2327030) (https://www.ltreb-reservoirs.org/vera4cast/). To date, 41,738 forecasts have been submitted to the VERA Challenge. Both of these new challenges use the cyberinfrastructure that was developed for the NEON forecasting challenge. Importantly, the RCN has coordinated the new challenges so that information and best practices are shared and that common standards are used. As a result of our work in previous years developing standards (Dietze et al. 2023) and collaboration with the NSF-funded DeCODER project (OAC-2209866), forecasts from all three challenges (NEON, USGS, and VERA) are all discoverable through a catalog interface (https://radiantearth.github.io/stac-browser/#/external/raw.githubusercontent.com/eco4cast/challenge-catalogs/main/catalog.json?.language=en) and a searchable interface (https://ecoforecast.geocodes-aws.earthcube.org)

Our second major activity was organizing ecological forecasting sessions and workshops at major society meetings. We sponsored two organized sessions and one workshop at the Ecological Society of America (ESA) meeting. Sessions: “Ecological Forecasting for Research and Decision Making” and “What is Model Complexity? Defining Complexity Across Systems in Ecology” and Workshop: “An Introduction to the NEON Ecological Forecasting Challenge: A Hands-On Example Using Ground Beetle Abundance and Richness”. We supported a session on ecological forecasting at the American Geophysical Union meeting: “Model-Data Integration and Novel Paradigms in Ecosystem Forecasting”. We organized an ecological forecasting session at the Association for the Sciences of Limnology and Oceanography (ASLO) 2024 conference: “Ecological Forecasting as a Tool for Adaptation and Mitigation in Aquatic Ecosystems”.

Our third major activity was general community-building activities that included the maintenance of a website, working group meetings, regular newsletters, blog posts, and an active Twitter feed. The Ecological Forecasting Initiative’s working groups revolve around Cyberinfrastructure & Methods & Tools; EFI Student Association; Theory; Education; Diversity, Equity, and Inclusion; Translation and Actionable Science; the Forecast Challenge Terrestrial Fluxes working groups, and a book group hosted by the Diversity, Equity, and Inclusion working group. There were 94 Zoom calls for these working group calls during the fifth year of the project. Eight blog posts on the ecoforecast.org website provided updates about activities supported by the Ecological Forecasting Initiative, sessions and talks at national conferences, an announcement of a new forecasting challenge, considerations for increasing inclusion in forecasting, and awards presented for forecasting papers and conference presentations. Updates were also sent to over

1,300 listserv members through nine newsletters. Finally, our Twitter feed (@eco4cast) has almost 2,300 followers. This year we had 56 tweets.

We hosted additional panel seminars and series that revolved around topics pertinent to the field of ecological forecasting. In particular, we continued our third and fourth sessions co-hosting a Statistical Methods Seminar series with the ESA Statistical Ecology Section that provided an overview of a statistical method and corresponding R package(s). Topics for this past year included stopped random walks using Stan, close-kin mark-recapture, wsyn: wavelet approaches to studying synchrony in ecology, SpaDES: a flexible tool to PERFICT your workflow, spatio-temporal modeling, applications of the aniMotum R package.

Key outcomes or Other achievements

Objective 1.

We collaborated with CSSI NSF grant (2209866), in collaboration with the GeoCODES community, to create an interface that will search the catalogs to improve the discoverability and re-use of ecological forecasts. The searchable interface is at https://ecoforecast.geocodes-aws.earthcube.org.

Objective 2.

We hosted and revised the NEON Ecological Forecasting Challenge (www.neon4cast.org). The process of hosting included generating a website describing the forecast challenge themes and rules; keeping the cyberinfrastructure running and constantly downloading NOAA and NEON data, processing submitted forecasts, scoring forecasts, and generating a dashboard describing the results. Our server ran the NSF-funded Jetstream Cloud computation and GitHub Actions computational environments. In total 198 teams have submitted 73,619 unique forecasts across the five themes. The Challenge is now fully built out and includes all 81 NEON sites. The Challenge will continue to run for the full length of the RCN project and serve as a focal point for the network. The Challenge has provided feedback to NEON that improves their data products, including reducing data latencies, expanding data products, and revising data products to correct anomalous data.

Objective 3.

First, we developed and revised publicly available training materials that have been used in two different workshops and two semester-long graduate courses in 2024. The workshop materials have been accepted by the *Journal of Open Source Education* (Olsson et al. 2024) and published on NEON Learning Hub. The graduate course materials are openly available via an online book (https://frec-5174.github.io/eco4cast-in-R-book/).

Objective 4.

We supported the creation of new software primarily by maintaining and enhancing the NEON Forecasting Challenge cyberinfrastructure (https://github.com/eco4cast/neon4cast-ci) and the R-package that generates STAC catalogs with metadata describing model submissions. A working group that started in the year 3 RCN unconference developed a prototype code to support a spatial forecast of LAI recovery post forest fire https://github.com/eco4cast/modis-lai-forecast

Objective 5.

We co-organized a 2.5-day workshop on community-designed forecasting cyberinfrastructure that was designed specifically to engage federal forecasting partners. Representatives from the USGS, NOAA, NASA, NERACOOS, ERDC USACE, ORNL DAAC were included in the workshop. Additionally, we hosted two workshops that provided training on how partner organizations can use the cyberinfrastructure developed by the RCN to run forecasting challenges (one virtual with almost 40 people expressing interest in joining the call, 18 attending the call, and another 18 views of the recorded materials and one in Finland at the Ecological Forecasting Initiative 2024 meeting with 16 attendees).

Our engagement with NEON as resulted in the Ecological Forecasting Initiative being specifically named in NEON's 5-year strategic plan: "Expand activities in new research arenas through targeted outreach emphasizing the broad utility of NEON's Research Support Services to facilitate piloting of new technologies and to support NSF-funded initiatives with emphasis on leading-edge computational approaches, such as the Ecological Forecasting Initiative, National Center for Atmospheric Research (NCAR), and the National Artificial Intelligence Research Resource Pilot".

Objective 6.

As discussed above, we published one paper synthesizing concepts in model complexity (Malmborg et al. 2024), published one paper highlighting the need for ecological forecasting to adapt and mitigate climate change (Dietze et al 2024), and had one paper accepted describing the water temperature and oxygen forecasting challenge (Olsson et al. Accepted).

Opportunities for training and professional development has the project provided?

Multiple opportunities for training and professional development have been provided by the RCN to the broader EFI community as well as specifically for graduate students and postdoctoral scholars. Across our workshops at professional meetings and virtual workshops, we engaged over 3,500 individuals in 2024.

First, our RCN has an active graduate student association (EFISA) that meets monthly, resulting in nine meetings over the past year. The group has had 47 individuals from 34 institutions participate overall with 19 individuals joining in this past year. Currently, the very active #students Slack channel has 155 participants. Graduate students have developed their own operating principles and procedures and defined the goal of the association to provide a

community of students who have expertise in a diverse array of fields, but who all share a common interest of improving and contributing to the development and application of ecological forecasts. As a result, knowledge exchange and community-building are two of their foremost goals. Along with these aims, the EFISA strives to serve the student community by developing technical and professional development skills, providing peer support, and advancing career aims.

Students and post-docs are leading and co-authoring manuscripts that were submitted for publication this year including Olsson et al. (accepted) and Malmborg et al. 2024. Two were submitted in the previous report but published this year (Wheeler et al 2024, Lewis et al. 2024).

Graduate students have gained professional leadership experience by serving on the RCN steering committee. Drew Villeneuve (University of New Hampshire) provided important guidance for making the RCN serve the needs of early career scientists and extensively helped coordinate the RCN activities.

The Challenge was used as the foundation of two workshops and two seminar-long graduate courses focused on graduate student, post-doc, and other ECR training (see Major activities for list). Early career participants Freya Olsson and Mary Lofton (Virginia Tech) have led workshops and assisted a team from Europe new to the forecasting challenge infrastructure to consider how to adapt the workflow to work for biodiversity target data for Doñana National Park. The goal is to have the workflow finalized for a workshop in February 2025.

The Statistical Methods webinar series that was co-hosted with the Ecological Society of America Statistical Ecology section provided an overview of seven statistical methods and advice for using and avoiding pitfalls for R packages used for those statistical methods (see Major activities for list).

Publications

Thomas, R.Q. 2024. A Practical Guide to Ecosystem Forecasting. https://frec-5174.github.io/eco4cast-in-R-book/

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Olsson, F., C. Boettiger, C.C. Carey, M. Lofton, R.Q. Thomas. 2024. Can you predict the future? A tutorial for the National Ecological Observatory Network Ecological Forecasting Challenge. Journal of Open Science Education. Submitted.

Dietze, M., E.P. White, A. Abeyta, C. Boettiger, N. Bueno Watts, C.C. Carey, R. Chaplin-Kramer, R.E. Emanuel, S.K.M. Ernest, R.J. Figueredo, M.D. Gerst, L.R. Johnson, M.A. Kenney, J.S. McLachlan, I.C. Paschalidis, J.A. Peters, C.R. Rollinson, J. Simonis, K. Sullivan-Wiley, R.Q. Thomas, G.M. Wardle, A.M. Willson, and J. Zwart. 2024. Near-Term Ecological Forecasting for Climate Change Action. *Nature Climate Change*. https://doi.org/10.1038/s41558-024-02182-0

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Record, N.R., C.C. Carey, J. Evanilla, O. Johnson, M. Lofton, K. Oliveira, F. Olsson, C. Ross, R.Q. Thomas, B. Tupper, and N. Hellessey. So you want to forecast: navigating multiple pathways to lower the barriers into ecological forecasting. In Review at *Earth Stewardship.*