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

January 11, 2024

This is a condensed and updated report from our annual report to the National Science Foundation in December 2023 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 fourth 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 three manuscripts directly related to the Challenge: a manuscript describing the forecasting challenge was published in the high-impact journal Ecological Society of America's *Frontiers in Ecology and Environment* (Thomas et al 2023a), a manuscript describing forecasting water temperature at NEON lakes was also published in *Frontiers in Ecology and Environment* (Thomas et al. 2023b), and a manuscript (lead by a post-doc) describing the results from the phenology forecasting challenge was accepted for publication in *Agricultural and Forest Meteorology* (Wheeler et al. Accepted).

We focused on growing the community of scientists forecasting using NEON data by providing 10 training workshops on ecological forecasting with NEON data that engaged over 310 individuals across career stages. These include workshops at the Europen Union InventWater Horizon 2020 Programme (January 2023), NEON Technical Working Group in Ecological Forecasting (February 2023), Global Change Ecology Lab at Center at University of Edinburgh (February 2023), Global Lakes Ecological Observatory Network (February 2023), Flux Course (June 2023), Aquatic Ecosystem MOdeling Network—Junior (AEMON-J) Hacking Limnology Workshop (July 2023), Canadian Ecological Forecasting Initiative Summer Training Course (July 2023), Ecological Society of America Annual Meeting (August 2023), and NEON Data Skills Virtual Workshop (October 2023). A post-doc developed training materials (https://github.com/OlssonF/NEON-forecast-challenge-workshop) that have been submitted to the Journal for Open Source Education. Other materials were developed specifically for the Flux Course (https://github.com/mdietze/FluxCourseForecast).

Overall, over the 4 years of the project, 222 teams have submitted 32,732 unique forecasts across the five themes. This is up from the 90 teams having submitted 6,874 unique forecasts through the 3rd year of the project. In total these forecasts resulted in 2,552,672 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 during the fourth year of the EFI-RCN was organizing an in-person meeting at NEON Headquarters that focused on developing tools, frameworks, and software for forecasting with NEON data. The meeting, titled "EFI 2023 Unconference" was held June 21-23 with the goal to work together on products such as developing forecasts, automating forecasts, developing teaching materials/tutorials, refining or creating software tools, analyzing forecasts for a manuscript, developing visualizations, or working on other activities proposed by the participants. The meeting was capped at 50 participants due to space constraints at NEON and we had many more apply to the meeting. Over 40% of the participants were early career and 22% were from underrepresented groups. Forty percent of the participants had not participated in prior EFI-RCN meetings, highlighting that we are continuing to grow the network. The group self-organized into 10 different project groups and each wrote a report that was shared through the EFI blog (https://bit.ly/efi-unconference-project-updates). The project teams are continue to meet virtually to finalize the development of software and manuscripts.

Our third major activity was organizing ecological forecasting sessions and workshops at major society meetings. We sponsored an organized session and two workshops at the Ecological Society of America (ESA) meeting. Session: "Ecological Forecasting: Applications, Discoveries, and Opportunities." Workshops: "Can You Predict the Future? Introducing the NEON Ecological Forecasting Challenge" and "Teach Quantitative Reasoning and Ecological Forecasting to Undergraduates with Project EDDIE and Macrosystems EDDIE Modules". We supported a session on ecological forecasting at the American Geophysical Union meeting: "Ecological Forecasting in the Earth System". We organized an ecological forecasting session at the Joint Aquatic Sciences Meeting: "Advancing Near-term, Iterative Ecological Forecasting in Aquatic Ecosystems" and taught a workshop at GLEON: "Introduction to real-time lake forecasting: learn, teach, and generate forecasts with Macrosystems EDDIE modules and the NEON Forecasting Challenge". Finally, we organized the "Combining Machine Learning and Process-Based Models in Ecological Prediction" session at the Association for the Sciences of Limnology and Oceanography conference.

Our fourth 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; Forecasting Standards; EFI Student Association; Theory; Education; Diversity, Equity, and Inclusion; Translation and Actionable Science; the Forecast Challenge Phenology and Terrestrial Fluxes working groups, and a book group related to diversity, equity, and inclusion. There were over 100 Zoom calls for these working group calls during the fourth year of the project. Nine blog posts on the ecoforecast.org website provided updates about the progress by the working groups to assess the translation needs of the EFI community, identify barriers to inclusion in forecasting, and provide recommendations from the book clubs for action items to support a diverse and inclusive community and design teams; highlights from the Unconference and subsequent Unconference working group updates about transporting models between NEON and non-NEON systems and recommendations for updated dashboard visualizations; awards presented for forecasting papers and conference

presentations. Updates were also sent to over 1,160 listserv members through nine newsletters. Finally, our Twitter feed (@eco4cast) has gained over 100 additional followers this year to give us over 2,000 followers. This year we had 73 tweets.

We hosted additional panel seminars and series that revolved around topics pertinent to the field of ecological forecasting. In particular, we continued our second and third 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 zero-inflated GLM and GLMM, spatial modeling in ecology, state space models and the Template Model Builder (TMB) R package, Bayesian stable isotope mixing models and the MixSIAR R package, integrated species distribution models, ecological forecasting with dynamic generalized additive models, and the HMSC R package, hierarchical modeling of species communities.

Key outcomes or Other achievements

Objective 1.

We published a manuscript describing a community-developed convention for saving forecast output and generating metadata describing the forecast. These standards are supported by software developed to help generate and validate the metadata. We used the NEON Ecological Forecasting Challenge and collaborations with the new Virginia reservoirs LTREB to test the standards. We also collaborated with the SpatioTemporal Asset Catalogs community to ensure interoperability in the standards across schemas. Finally, 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. As it is finalized, the searchable interface will be 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 222 teams have submitted 32,732 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 serves 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 (https://github.com/OlssonF/NEON-forecast-challenge-workshop) that have been used in nine different workshops during 2023. The materials have been submitted to the *Journal of Open Source Education* (Olsson et al. submitted) . Second, we submitted a manuscript to the journal *Teaching Issues and Experiments in Ecology* that uses case studies to teach ethical considerations in ecological forecasting (Lewis et al. accepted). Third, we had a paper published in a peer-reviewed journal that explored the gaps in undergraduate education in forecasting (Willson et al. 2023). Finally, in collaboration with the Macrosystem EDDIE project, we published a manuscript describing a teaching module on forecast visualization, uncertainty, and decision support. The module was used and tested by many in the EFI-RCN community (Woelmer et al 2023).

Objective 4.

We supported the creation of new software primarily by hosting the EFI 2023 Unconference. The 2023 EFI Unconference, hosted by the Ecological Forecasting Initiative Research Coordination Network (EFI RCN) and supported by the National Science Foundation, brought together 45 passionate individuals at NEON's headquarters in Boulder, CO on June 21-23, 2023 to work on a diverse range of projects that were nominated and selected by the participants. With a focus on collaborative problem-solving, the Unconference fostered a unique environment for participants to exchange knowledge, generate new approaches, and advance the field of ecological forecasting.

In addition to project development, activities included a warm welcome from Kate Thibault, NEON Science Lead, icebreaker activities, expertly facilitated by Cayelan Carey from Virginia Tech that helped participants connect and form meaningful relationships, a tour of NEON facilities, and a poster session and social hour, where participants showcased their research and projects. Through these activities, Unconference participants and NEON staff were able to engage with one another, exchange feedback, and forge new collaborations.

To ensure a productive and focused Unconference, participants engaged in a review of project ideas and subsequent project selection. This process allowed attendees to propose projects aligned with their interests and expertise and fostered a sense of ownership and investment in the outcomes. Ten project groups developed out of the 24 that were initially proposed as part of the pre-meeting preparation.

The groups were the following: Spatially Explicit Forecasting, Forecast uncertainty, Forecasting Impacts: Measuring the Current and Future Impacts of EFI, Reenvisioning the NEON Ecological Forecasting Challenge Dashboard Visualization, Transporting Models Between NEON and non-NEON Systems, ML-based Uncertainty in the NEON Ecological Forecasting Challenge, Forecasting Ground Beetles: Avoiding Pitfalls, Towards Principles for Designing Inclusive

Ecological Forecasts, A proactive step toward decision-ready forecasts: Fusing iterative, near-term ecological forecasting and adaptive management, Disease Forecasting

This was the first in-person EFI-RCN event since 2019 and it was absolutely lovely to be in the same room to meet new people and to see in-person people we had only seen on Zoom before.

Objective 5.

We continued to co-develop the expanded aquatics theme in the NEON Ecological Forecasting Challenge with the USGS. This involved expanding the number of sites in the Challenge to include river sites and a new variable (chlorophyll-a) that were specially identified by the USGS as priorities. We also started a collaboration with a newly funded NSF-funded LTREB (DEB-2327030) focused on forecasting drinking water reservoirs managed by a regional water authority.

Objective 6.

As discussed above, we published a paper explores how predictability varies across NEON lake sites (Thomas et al. 2023), published a paper that provides an overview of the NEON Forecasting Challenge (Thomas et al. 2023), and had a paper accepted that describes the results from the phenology theme (Wheeler et al.).

Opportunities for training and professional development

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.

First, our RCN has an active graduate student association (EFISA) that meets monthly, resulting in 10 meetings over the past year. The group has had 70 individuals from 48 institutions participate overall with 20 individuals joining in this past year. Currently, the #students Slack channel has over 140 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.

EFISA hosted a panel on career pathways for students and early career scientists in February to highlight career paths in alternative careers outside of academia. Panelists participated from multiple government sectors and environmental nonprofits.

Our EFI 2023 Unconference meeting included five graduate students and fourteen post-docs. The meeting provided opportunities for graduate students and postdocs to share research through posters and network with others in the ecological forecasting community through intensive collaboration.

One post-doc (Freya Olsson at Virginia Tech) is leading the training, recruitment, and synthesis of the aquatic theme in the NEON Ecological Forecasting Challenge.

Students and post-docs are leading and co-authoring manuscripts that were submitted and accepted for publication this year including Woelmer et al. 2023, Lofton et al. 2023, Smith et al 2023ab, Willson et al. 2023, Wheeler et al. (accepted), Lewis et al. (accepted), Olsson et al. (submitted), and Malmborg et al. (submitted).

Graduate students have gained professional leadership experience by serving on the RCN steering committee. Lynda Bradley (Emory University) provided important guidance for making the RCN serve the needs of early career scientists and extensively helped to coordinate the RCN meeting in June, including student-focused networking event.

The Challenge was used as the foundation of ten workshops focused on graduate student, post-doc, and other ECR training (see Major activities for list).

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

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