

Module 5: Introduction to Ecological Forecasting - Student Handout



Name:

Student ID:

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Macrosystems EDDIE Module 5: Introduction to Ecological Forecasting

Learning Objectives:

By the end of this module, you will be able to:

- Describe an ecological forecast and the iterative forecasting cycle
- Explore and visualize NEON data using an R Shiny interface
- Construct an ecological model to generate forecasts of ecosystem primary productivity with uncertainty
- Adjust model parameters and inputs to study how they affect forecasts relative to observations
- Compare productivity forecasts among NEON sites in different regions

Why macrosystems ecology and ecological forecasting?

Macrosystems ecology is the study of ecological dynamics at multiple interacting spatial and temporal scales (e.g., Heffernan et al. 2014). For example, *global* climate change can interact with *local* land-use activities to control how an ecosystem changes over the next decades. Macrosystems ecology recently emerged as a new sub-discipline of ecology to study ecosystems and ecological communities around the globe that are changing at an unprecedented rate because of human activities (IPCC 2013). The responses of ecosystems and communities are complex, non-linear, and driven by feedbacks across local, regional, and global scales (Heffernan et al. 2014). These characteristics necessitate novel approaches for making predictions about how

systems may change to improve both our understanding of ecological phenomena as well as inform resource management.

Forecasting is a tool that can be used for understanding and predicting macrosystems dynamics. To anticipate and prepare for increased variability in populations, communities, and ecosystems, there is a pressing need to know the future state of ecological systems across space and time (Dietze et al. 2018). Ecological forecasting is an emerging approach which provides an estimate of the future state of an ecological system with uncertainty, allowing society to prepare for changes in important ecosystem services. Ecological forecasts are a powerful test of the scientific method because ecologists make a hypothesis of how an ecological system works; embed their hypothesis in a model; use the model to make a forecast of future conditions; and then when observations become available, assess the accuracy of their forecast, which indicates if their hypothesis is supported or needs to be updated. Forecasts that are effectively communicated to the public and managers will be most useful for aiding decision-making. Consequently, macrosystems ecologists are increasingly using ecological forecasts to predict how ecosystems are changing over space and time (Dietze and Lynch 2019).

In this module, students will apply the iterative forecasting cycle to develop an ecological forecast for a National Ecological Observation Network (NEON) site of their choice. This module will introduce students to the basic components of an ecological forecast; how a forecasting model is constructed; how changes to model inputs affect forecast uncertainty; and how productivity forecasts vary across ecoclimatic domains.

Module overview:

- Introduction to Ecological Forecasting: pre-readings and PowerPoint in class
- Activity A: Visualize data from a selected NEON site and build an ecological model
- Activity B: Generate a forecast and work through each stage of the iterative forecast cycle
- Activity C: Apply a forecast to a different NEON site and compare forecasts among sites

Today's focal question: *What is an Ecological Forecast?*

To address this question, we will introduce ecological forecasts and the iterative forecasting cycle. We will build a model that forecasts aquatic ecosystem productivity in response to multiple environmental factors (e.g., weather, herbivory). We will also examine the uncertainty associated with our forecast predictions, which can originate from multiple sources. In this module, we will use our productivity model to examine how forecast uncertainty is related to driver data, model parameters, and initial conditions. We will then compare productivity forecasts for ecosystems in different ecoclimatic regions to understand how forecasts can vary both over time and space.

We will be using ecological data collected by the National Ecological Observation Network (NEON) to tackle this question. NEON is a continental-scale observatory designed to collect publicly-available, long-term ecological data to monitor changing ecosystems across the U.S. Primary productivity in lakes is our focal forecast variable as it is a key indicator of ecosystem

health and can change rapidly in response to environmental drivers. We will use measurements of chlorophyll-a as a proxy measurement of aquatic primary productivity.

R Shiny App:

The lesson content is hosted on an R Shiny App at

<https://macrosystemseddie.shinyapps.io/module5/>

This can be accessed via any internet browser and allows you to navigate through the lesson via this app. You will fill in the questions below on this handout as you complete the lesson activities.

Optional pre-class readings and video:

Webpages:

- [NOAA Ecological Forecasts](#)
- [Ecological Forecasting Initiative](#)

Articles:

- Dietze, M. and Lynch, H. 2019. Forecasting a bright future for ecology. *Frontiers in Ecology and the Environment*, 17(1), 3. <https://doi.org/10.1002/fee.1994>
- Dietze, M.C., et al. 2018. Iterative near-term ecological forecasting: Needs, opportunities, and challenges. *Proceedings of the National Academy of Sciences*, 115(7), 1424–1432. <https://doi.org/10.1073/pnas.1710231115>
- Jackson, L.J., Trebitz, A.S., & Cottingham, K.L. 2000. An introduction to the practice of ecological modeling. *BioScience*, 50(8), 694. [https://doi.org/10.1641/0006-3568\(2000\)050\[0694:aittpo\]2.0.co;2](https://doi.org/10.1641/0006-3568(2000)050[0694:aittpo]2.0.co;2)

Videos:

- NEON's [Ecological Forecast: The Science of Predicting Ecosystems](#)
- Fundamentals of Ecological Forecasting Series: [Why Forecast?](#)

The questions you must answer are embedded in the Shiny interface. You can answer the questions there and generate a report at the end or you can fill out the questions within this document.

Think about it!

Answer the following questions:

1. How have you used forecasts (ecological, political, sports, any kind!) before in your day-to-day life?

Answer:

2. How can ecological forecasts improve both natural resource management and ecological understanding?

Answer:

3. How do you think forecasts of freshwater primary productivity will differ between warmer lakes and colder lakes?

Answer:

Now navigate to the [Shiny interface](#) to answer the rest of the questions.

Exploration

Examples of ecological forecasts:

- [USA-NPN Pheno Forecast](#) - The USA National Phenological Network (NPN) Pheno Forecast delivers short-term (6 day) threshold-based forecasts of phenological events in plants and pest insects.
 - [Smart & Connected Water Systems](#) - A project which is developing a smart water system that integrates novel high-frequency sensors, cyberinfrastructure, and ecosystem forecasting techniques to improve the management of drinking water supply lakes and reservoirs.
 - [EcoCast](#) - EcoCast is a fisheries sustainability tool that helps fishers and managers evaluate how to allocate fishing effort to optimize the sustainable harvest of target fish while minimizing bycatch of protected or threatened animals.
 - [Atlantic Sturgeon Risk of Encounter](#) - This forecast is developed for mature Atlantic Sturgeon using historic telemetry observations matched to date, bathymetry, and sea surface temperature and ocean color from NASA's MODIS AQUA satellite.
 - [Grassland Production Forecast](#) - Grass-Cast uses almost 40 years of historical data on weather and vegetation growth - combined with seasonal precipitation forecasts - to predict if rangelands are likely to produce above-normal, near-normal, or below-normal amounts of vegetation.
 - [Portal Project - Rodent Abundances](#) - Forecasting a time series of rodent abundances from The Portal project, a long-term experimental monitoring project in desert ecology, 12 months into the future.
4. Choose one of the ecological forecasts above and use the website to answer the questions below.

- a. Which ecological forecast did you select?

Answer:

- b. What ecological variable(s) are being forecasted?

Answer:

- c. How can this forecast help the public and/or managers?

Answer:

- d. Describe the way(s) in which the forecast is visualized

Answer:

Activity A: Get Data & Build Model

Objective 1: Select and view site

Select a NEON site from the table, then click on the “View live feed” button to load the latest image from that site. Follow the link at the bottom of the ‘About Site’ section to find out more about the site.

5. Fill out information about your selected NEON site:

Table 1. Site Characteristics

Name of selected site:

Four letter site identifier:

Latitude:

Longitude:

Lake area (km²):

Figure 1. Phenocam image downloaded for .

Objective 2: Explore data

Explore the data measured at the selected site. This is data that has been downloaded from the NEON Data Portal. The variables shown have been selected for this module but there are a wide range of variables collected at each NEON site.

6. Fill out the table below with the description of site variables:

Table 2. Description of site variables:

Variable	Mean	Minimum	Maximum
Air temperature			
Water temperature profile			
Nitrogen			
Underwater PAR			
Chlorophyll-a			

Objective 3: Explore variable relationships

We will use chlorophyll-a sensor data to estimate primary productivity. Chlorophyll-a concentrations are an indicator of phytoplankton abundance and biomass. Explore the options below to see if there are any relationships between chlorophyll-a and the other variables measured at your site. This information will be used to build your model.

7. Describe the effect of each of the following variables on chlorophyll-a. Chlorophyll-a is used as a proxy measurement for phytoplankton concentration and primary productivity in aquatic environments.

Table 3. Description of effect of each variable on chlorophyll-a

Variable	Relationship
Air temperature	
Water temperature profile	
Nitrogen	
Underwater PAR	

8. Were there any other relationships you found at your site? If so, please describe below.

Answer:

Objective 4: Understand model

Using your understanding of aquatic ecosystems, you will build a simple ecological model to predict primary productivity.

9. What is the relationship between each of these driving variables and productivity? For example, if the driving variable increases, will it cause productivity to increase (positive), decrease (negative), or have no effect (stay the same).
 - a. Surface water temperature:
 - b. Incoming light:
 - c. Available nutrients:
10. State variables are those that give a snapshot of the system's properties at any single point in time. The phytoplankton biomass and nutrient concentration of an ecological model are examples of this. You can measure them, and you don't need any information about precisely how the system arrived in its current state. A parameter is a variable describing the rate of change in those states. Classify the following as either a state variable or a parameter by dragging it into the corresponding bin.

Table 4. Sorted parameters and state variables.

State variables	Parameters
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11. We are using chlorophyll-a as a proxy of aquatic primary productivity. Select how you envision each parameter to affect chlorophyll-a concentrations:
 - a. Nutrient uptake by phytoplankton:
 - b. Phytoplankton mortality:

Objective 5: Build model

Test different scenarios with your model to understand how it will respond under different environmental conditions. Use observed data to calibrate the model (i.e. make your model better match observed data).

Table 5. Parameters used in Q12-15

	SWT	uPAR	Phytoplankton	Zooplankton	Nutrients	Grazing	Mortality	Uptake
Q12								
Q13a								
Q13b								
Q14								
Q15								

12. Without using surface water temperature or underwater light (uPAR) as inputs into your model, adjust the initial conditions and parameters of your model to best replicate the observations. Make sure you select the 'Q12' row in the parameter table to save your setup. Describe how the model simulation compares to the observations.

Answer:

13. Explore the model's sensitivity to SWT and uPAR:

- a. Switch on surface water temperature by checking the box. Adjust initial conditions and parameters to replicate observations. Is the model sensitive to SWT? Did it help improve the model fit? (Select the "Q13a" row in the Parameter Table to store your model setup there).

Answer:

- b. Switch on uPAR and switch off surface water temperature. Adjust initial conditions and parameters to replicate observations. Is the model sensitive to uPAR? Did it help improve the model fit? (Select the "Q13b" row in the Parameter Table to store your model setup there).

Answer:

14. Develop a scenario (e.g. uPAR is on, low initial conditions of phytoplankton, high nutrients, phytoplankton mortality is high, low uptake, etc.) and hypothesize how you think chlorophyll-a concentrations will respond prior to running the simulation. Switch

off observations prior to running the model.

- a. Write your hypothesis of how chlorophyll-a will respond to your scenario here:

Answer:

- b. Run your model scenario. Select the “Q14” row in the Parameter Table to store your model setup there. Was your hypothesis supported or refuted? Describe what you observed:

Answer:

15. Add the observations to the plot. Calibrate your model by selecting sensitive variables and adjusting the parameters until they best fit the observed data. Save the plot and the parameters (Select the “Q15” row in the Parameter Table to store your model setup there), these are what will be used for the forecast.

Activity B: Forecast!

Objective 6: Examine uncertainty

Gain an understanding of what uncertainty is in the context of an ecological forecast and explore weather forecast data. Demonstrate how uncertainty can be quantified.

16. What is forecast uncertainty? How is forecast uncertainty quantified?

Answer:

17. Inspect the weather forecast data for the site you have chosen:

- a. How does increasing the number of ensemble members in the weather forecast affect the size of the uncertainty in future weather?

Answer:

- b. Which type of plot (line or distribution) do you think visualizes the forecast uncertainty best?

Answer:

- c. Using the interactivity of the weather forecast plot, compare the air temperature forecasts for the first week (Sep 25 - Oct 1) to the second week (Oct 2 - 8). How does the forecast uncertainty change between the two periods?

Answer:

Objective 7: Prepare inputs

Using the observed data from the site, you will build a linear model to convert air temperature to surface water temperature and shortwave radiation (SWR) to underwater photosynthetic active radiation (uPAR). This will allow you to then use the weather forecast data to generate a forecast with your ecological model.

Linear Regression

Linear regression models the relationship between two variables by fitting a linear equation to observed data. One variable (x) is a predictor variable, and the other is a response variable (y). For example, we will model surface water temperature (the response variable) using air temperature as a predictor variable.

The equation form for a linear regression is:

$$y = mx + b$$

Linear regression equation for surface water temperature and air temperature:

Please enter the values for “m” and “b” below:

$$wtemp = m * airtemp + b$$

Linear regression equation for underwater PAR (uPAR) and shortwave radiation (SWR):

Please enter the values for “m” and “b” below:

$$uPAR = m * SWR + b$$

Objective 8: Forecast

Use the weather forecast data which has been converted into driving variables (surface water temperature and underwater PAR) to drive the ecological models built in Objective 5 to forecast primary productivity.

18. How does driver uncertainty affect the forecast, specifically, does an increase in the number of members increase or decrease the range of uncertainty in the forecasts? How does that change over time?

Answer:

19. What do you think are the main sources of uncertainty in your ecological forecast?

Answer:

Objective 9: Communicate forecast

Forecasts that are effectively communicated to the public and managers will be most useful for aiding decision-making. Here you will think about how to communicate your forecast to an end-user.

20. How would you describe your forecast of primary productivity at your NEON site so it could be understood by a fellow classmate?

Answer:

Objective 10: Assess forecast

A fundamental part of the forecast cycle is assessing how well your forecast performed relative to observations. Here we will use a simple assessment of plotting forecast results against observations.

21. How well did your forecast do compared to observations? (include R^2 value) Why do you think it is important to assess the forecast?

Answer:

Objective 11: Update model

Update our model/hypothesis to improve our forecasts based on the recent observations that have been collected. Ecological forecasters call this recalibration of a model.

22. Did your forecast improve when you updated your model parameters? Why do you think it is important to update the model?

Answer:

Objective 12: Next forecast

The forecast cycle is an iterative process. Now after communicating and assessing our forecast and updating our model, we will now generate the next forecast. Ecological forecasters call this data assimilation because data are “assimilated” to update the initial conditions.

23. Describe the new forecast of primary productivity.

Answer:

24. Why is the forecast cycle described as ‘iterative’ (i.e. repetition of a process)?

Answer:

Table 6. Model settings used in the first forecast, updated forecast and the second forecast.

	SWT	uPAR	Phytoplankton	Nutrients	Mortality	Uptake
Forecast 1						
Updated Forecast						
Forecast 2						

Activity C: Scale

Objective 13: Compare productivity forecasts between two different NEON sites

Make a hypothesis about how you expect your model to forecast primary productivity at a different NEON site. Then test your hypothesis by repeating Activity A Objectives 1 & 5 and Activity B with the other NEON site.

25. Repeat Activity A and B with a different NEON site (ideally from a different region).
- Apply the same model scenario (with the same model structure and parameters) which you developed in Q14 to this new site. How do you expect chlorophyll-a concentrations will respond prior to running the simulation?

Answer:

- Was your hypothesis supported or refuted? Why?

Answer:

- Revisit your hypothesis from Q3, what did you find out about the different productivity forecasts in warmer vs colder sites?

Answer:

26. Does forecast uncertainty differ at this site compared to the first selected site? Why do you think that is?

Answer:

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