

# Macrosystems EDDIE: Introduction to Ecological Forecasting

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Macrosystems EDDIE: Introduction to Ecological Forecasting.

Macrosystems EDDIE Module 5, Version 1.

<http://module5.macrosystemseddie.org>

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# Overview of today

- Introducing the concepts of ecological forecasting, forecasting applications, and the iterative forecast cycle
- **Activity A:** Get data from an ecological site and build an ecological model to simulate ecosystem productivity
- **Activity B:** Step through each stage of the forecast cycle and generate an ecological forecast
- **Activity C:** Compare how ecosystem productivity forecasts differ among sites from different climatic regions

# Ecosystems are changing worldwide...

- In response to changes in the climate and land use, aquatic and terrestrial systems are experiencing different pressures which affect productivity
- Lakes and reservoirs are key providers of ecological services and understanding how they will change in the short-term is critical to help management of these resources

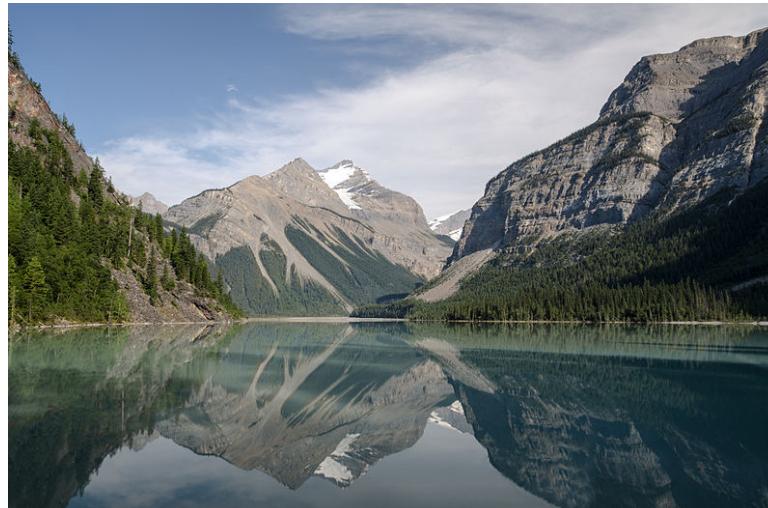


Image: Wikimedia commons

# Before we start

## What is a Forecast?

*“A forecast is a prediction of a future event with uncertainty”*

- Events have not yet occurred
- Gives a probability or a likelihood of the event to occur (uncertainty)
- Actionable

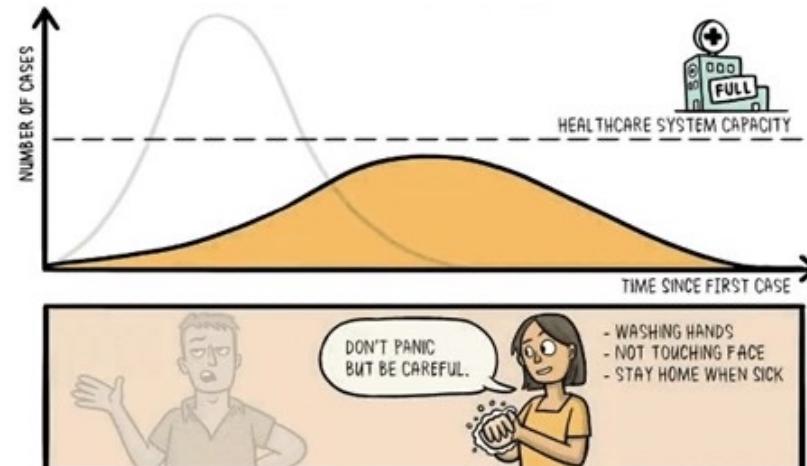
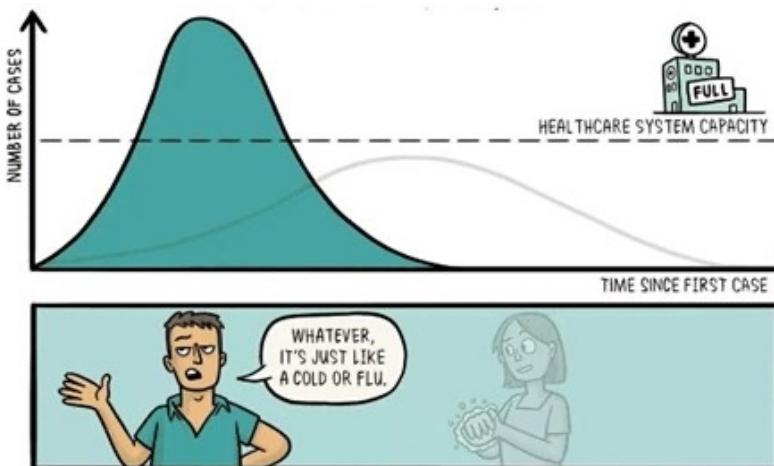
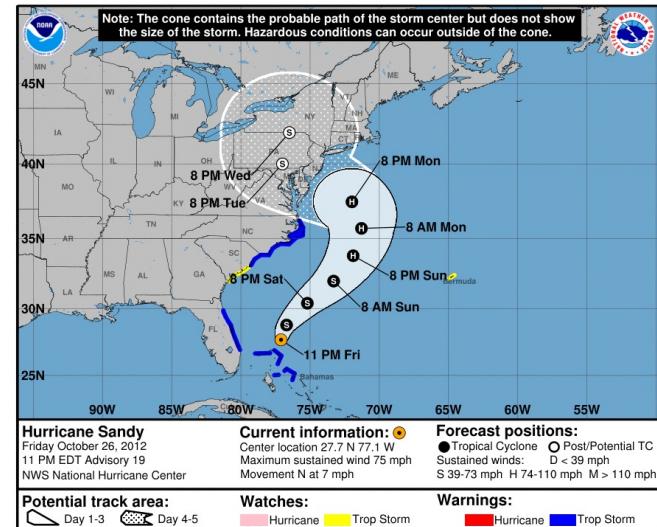
# Before we start

## What do we Forecast?

- Weather
- Floods
- Hurricanes
- Forest fires
- Economy
- Disease transmission
- Election results
- Greenhouse gas emissions
- Earthquakes
- Land use
- Player and team performance in sports
- Sales
- Transport planning
- and much more!

# What is the purpose of a forecast?

- Preparation
  - e.g. weather forecast - hurricanes
- Action
  - e.g. disease forecasting, fire forecasts



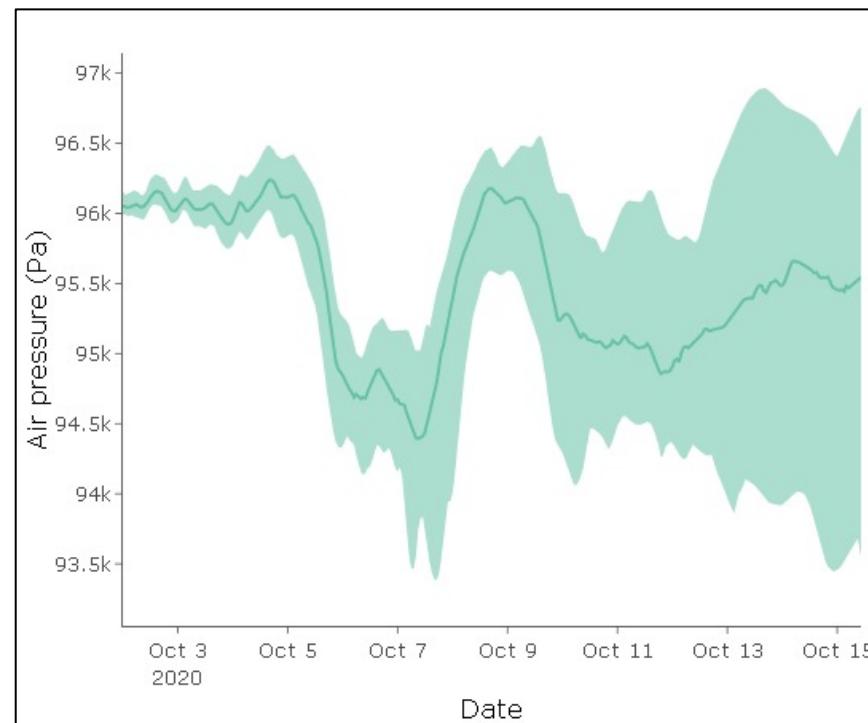
**Our focal question:**

What is an Ecological Forecast?

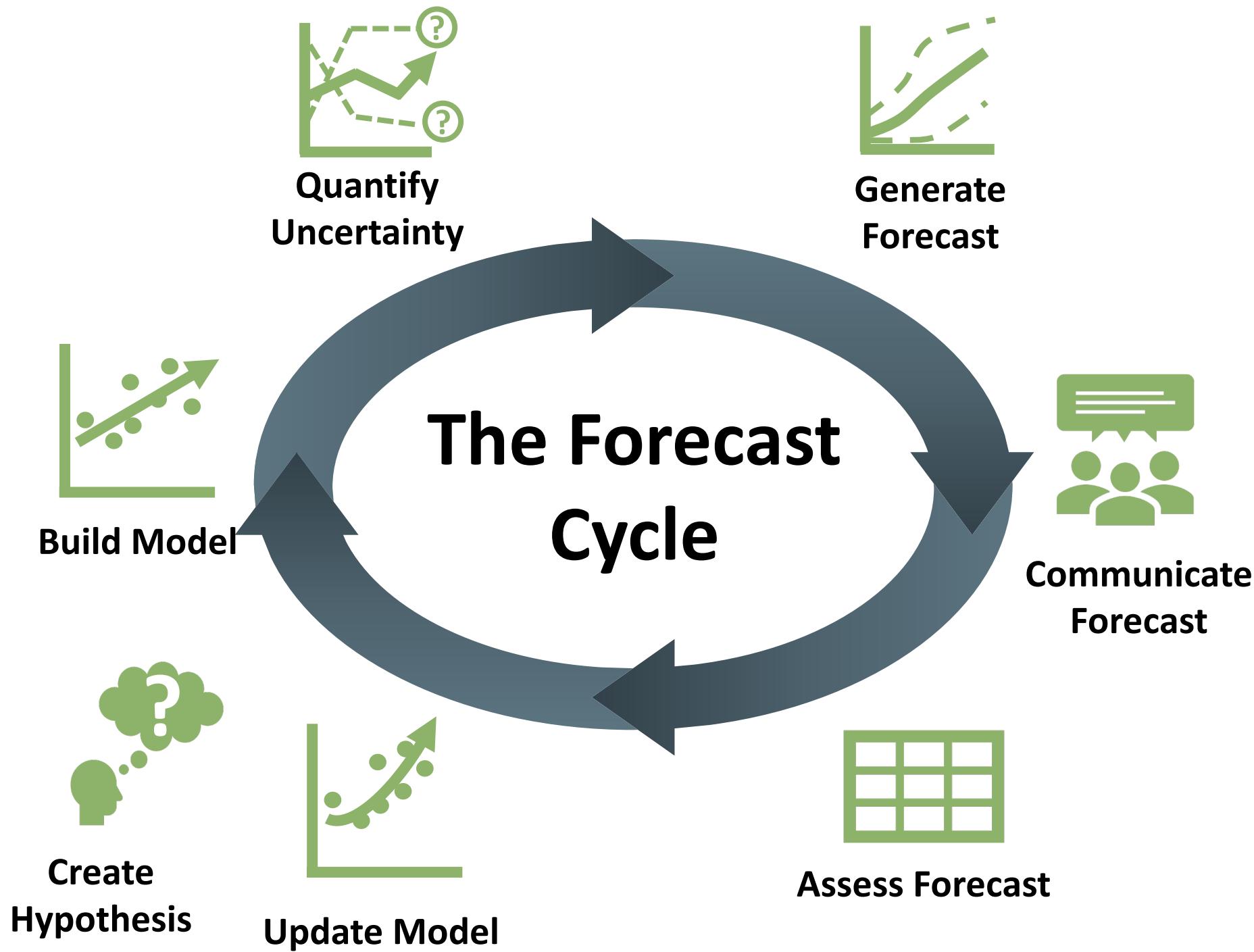
*“Prediction of future environmental conditions with uncertainty”*

# Uncertainty

- A forecast is a well-informed guess of the future; therefore, it will always be uncertain
- It is at the core of how people evaluate risk and make decisions
- Uncertainty generally increases with time into the future

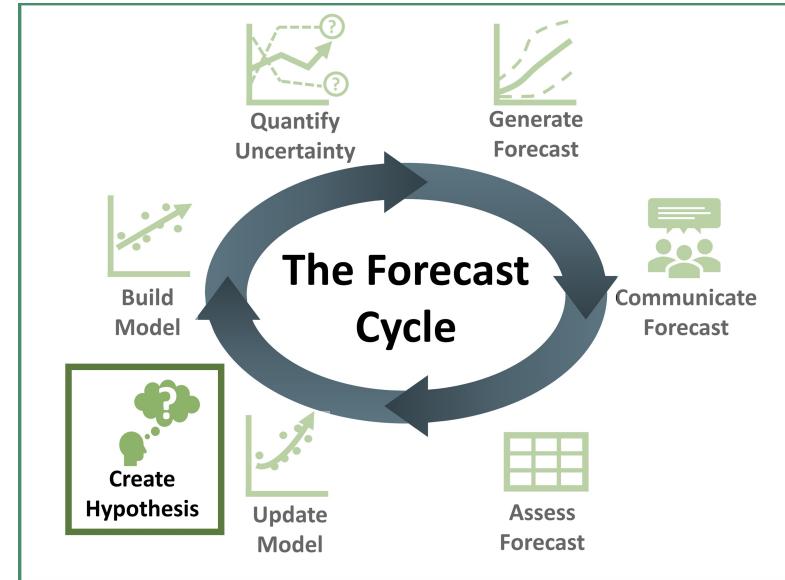


*Plot showing 16 day forecast of air pressure with shaded regions showing 95% confidence interval and the solid line represents the median*



# Create Hypothesis

A hypothesis is an idea that proposes an explanation about a phenomenon observed in the natural world

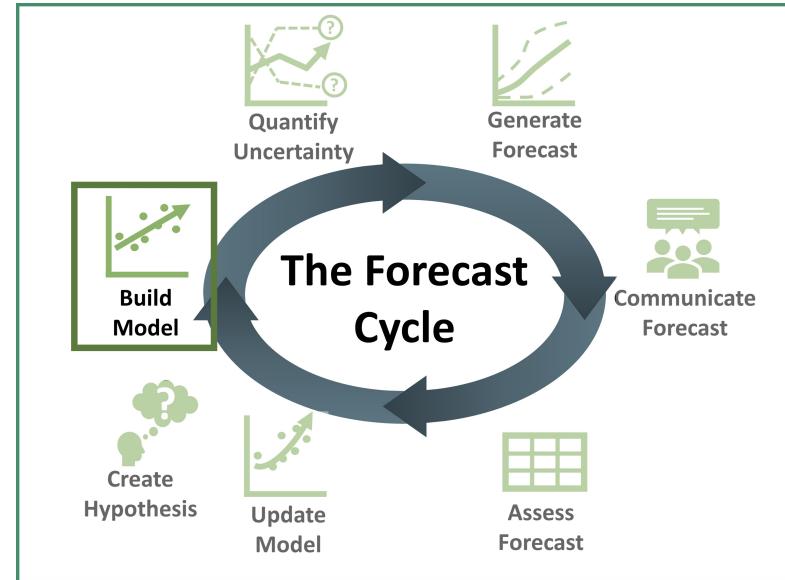


E.g., more light will increase the algal biomass in a lake

# Build Model

Using observational data,  
we can build a  
mathematical model to  
describe what is  
happening

E.g.,



$$phyto_t = phyto_{t-1} + \text{uptake} - \text{mortality}$$

Amount of  
Phytoplankton  
today

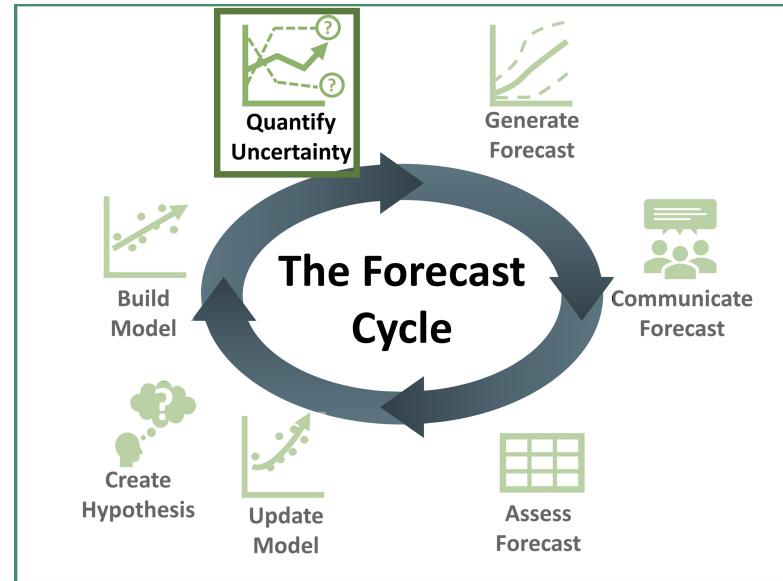
Amount of  
Phytoplankton  
yesterday

Nutrient  
uptake

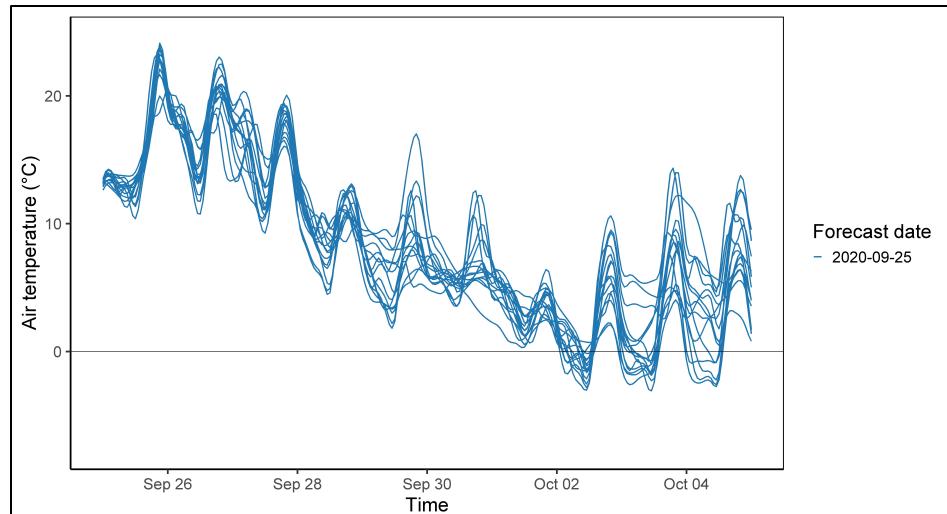
Phytoplankton  
death

# Quantify Uncertainty

Characterization and reduction of the uncertainties in the forecast



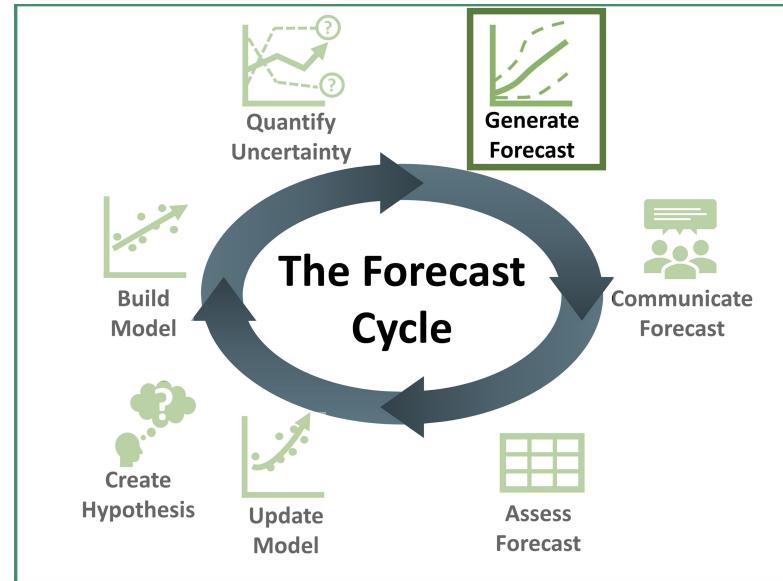
E.g., future weather isn't known exactly, so we use many different scenarios to forecast it, and then can quantify differences among scenarios as part of overall forecast uncertainty



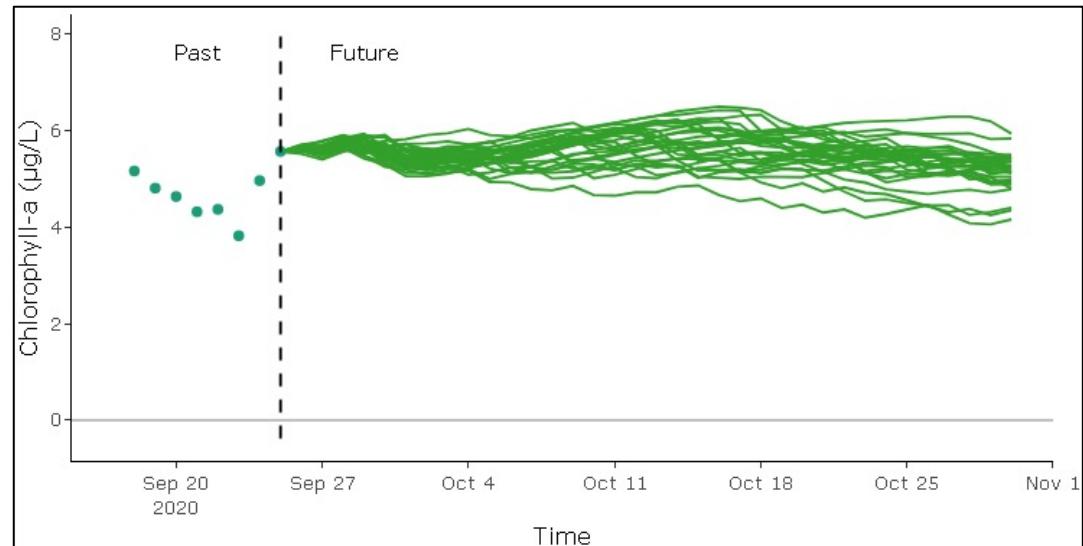
*Plot showing 10 day forecast of air temperature with each line representing a different forecast ( $n = 15$ )*

# Generate Forecast

Generate a forecast into the future using the model that has been built and using forecasted driver data

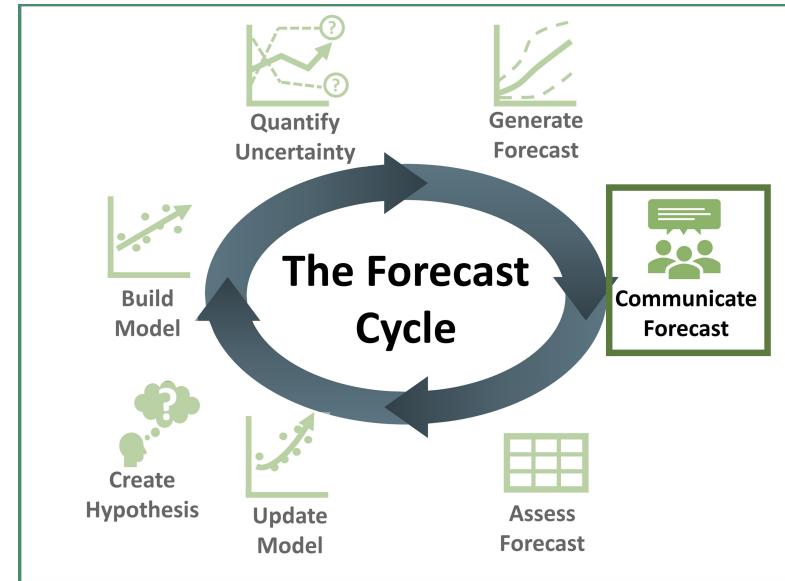


*Plot showing 35 day forecast of primary productivity (chlorophyll-a) with each line representing a different forecast ( $n = 30$ )*



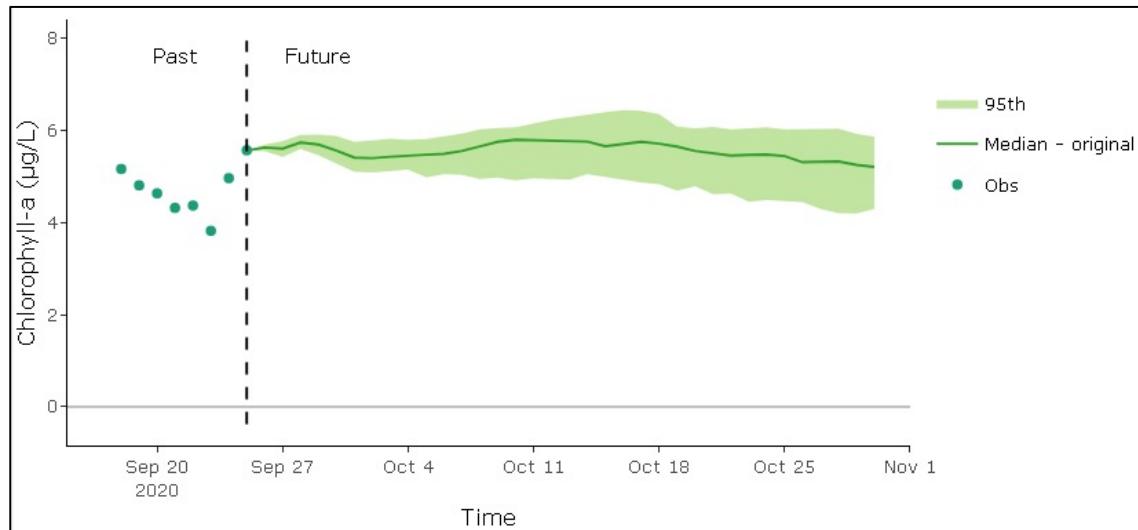
# Communicate Forecast

Communicate the forecast  
to stakeholders and  
potential end-users



E.g., create visualizations  
of the data to aid in  
forecast interpretation

*Plot showing 35 day forecast of primary productivity (chlorophyll-a) where the solid line represents the median and the shaded region is the 95% confidence interval (n = 30)*

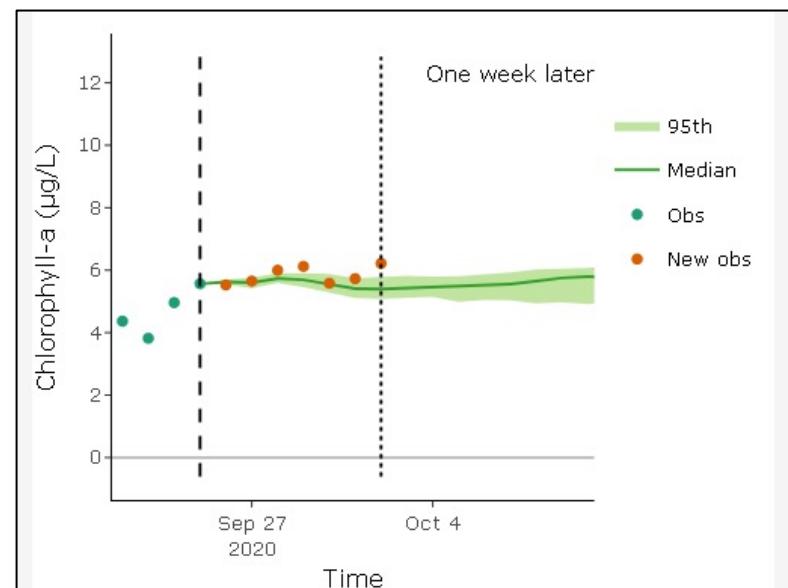
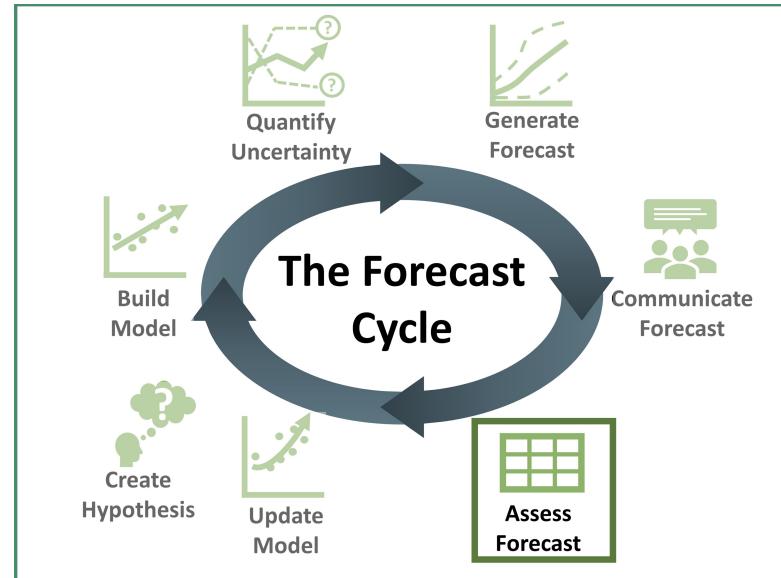


# Assess Forecast

As time moves forward and new data are collected, the forecast can be compared to the data to see how well it performed

E.g., using statistical or visual measures

*Plot showing the comparison of new observations (orange points) to the forecast of primary productivity (chlorophyll-a)*

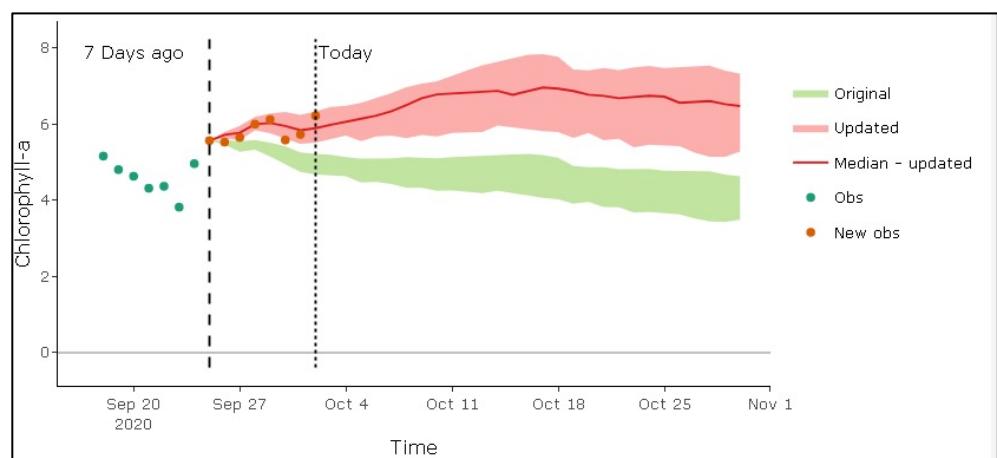
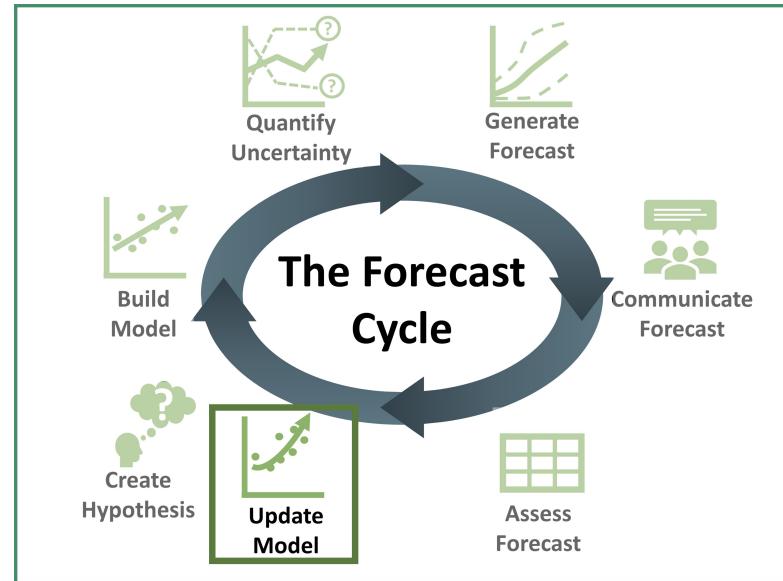


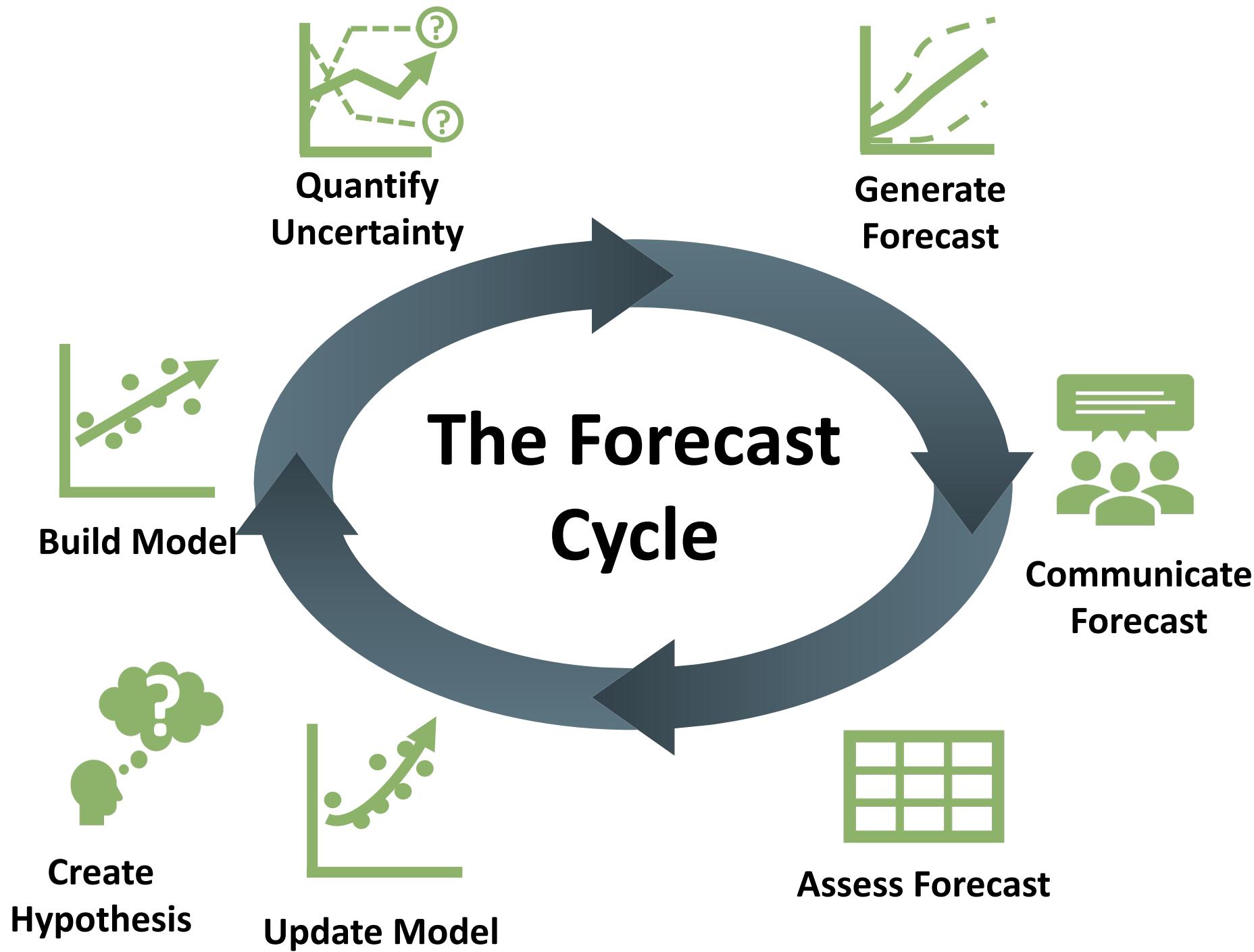
# Update Model

If the forecast did not perform well vs. observations, the model can be updated before generating a new forecast

E.g., updating the model parameters

*Plot showing an updated forecast (red) by updating the model parameters and the original forecast (green)*



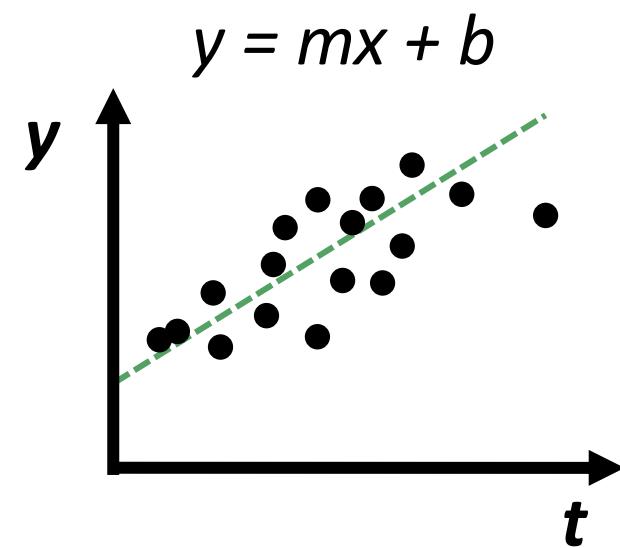
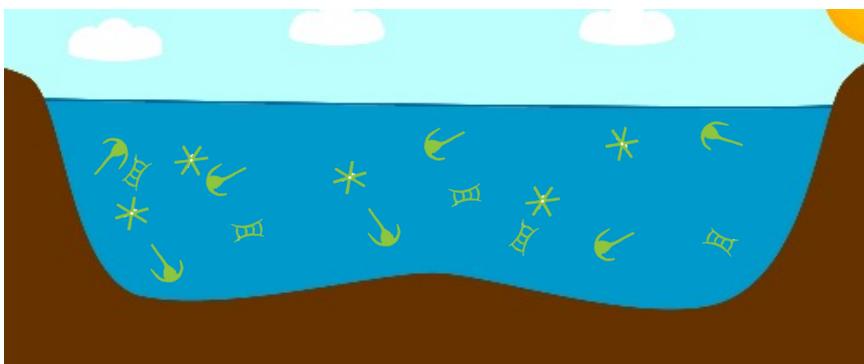


# Today...

We are going to use a **model** to generate a forecast of primary productivity in **lakes** using real **data**

A model is a representation of a real phenomenon that is difficult to observe directly, with the goal of understanding and **predicting** that phenomenon

Predicting chlorophyll-a concentrations in a lake



# What are the drivers of primary productivity in a lake?

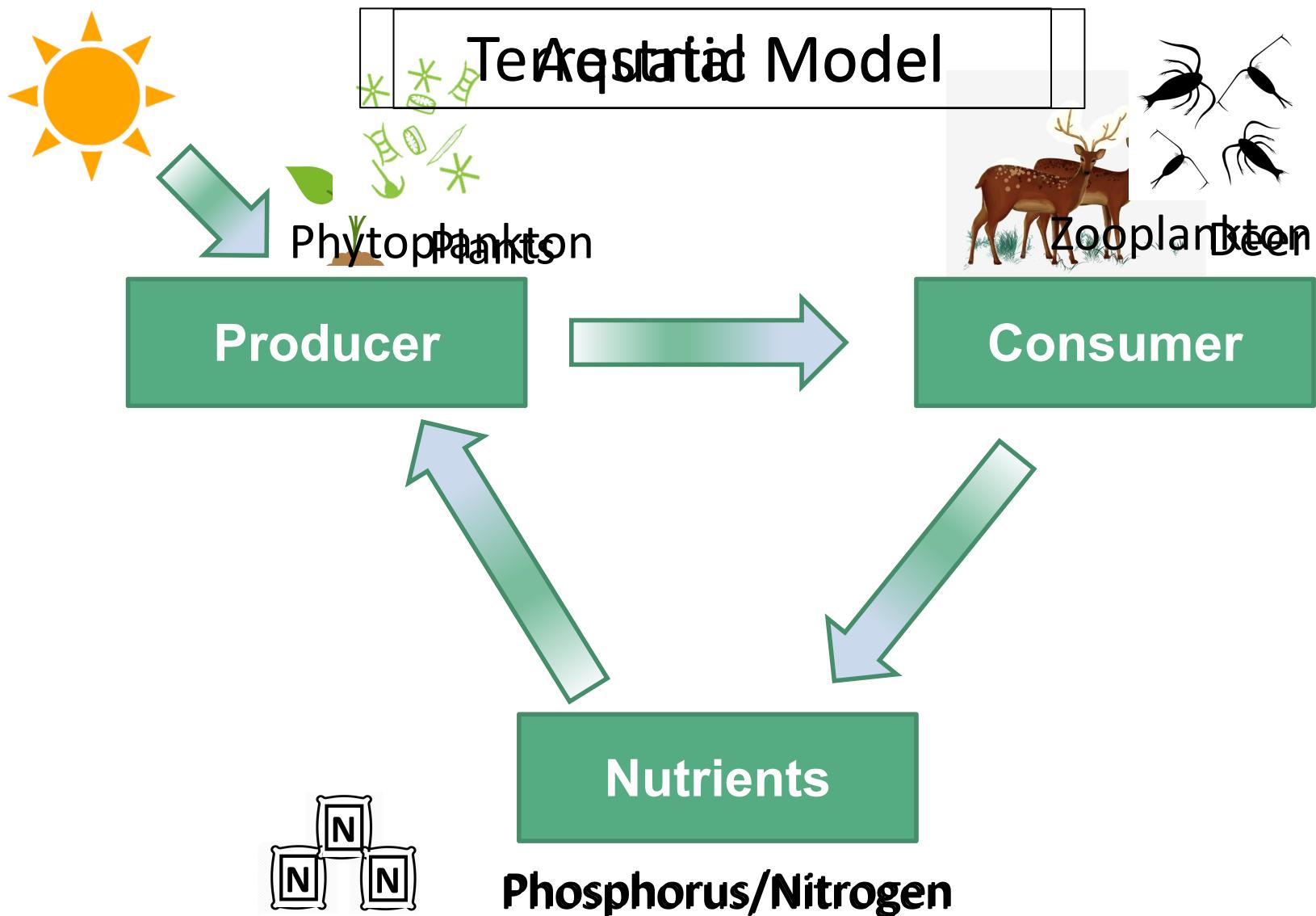
- Light
- Water temperature
- Available nutrients
- Phytoplankton
- Zooplankton



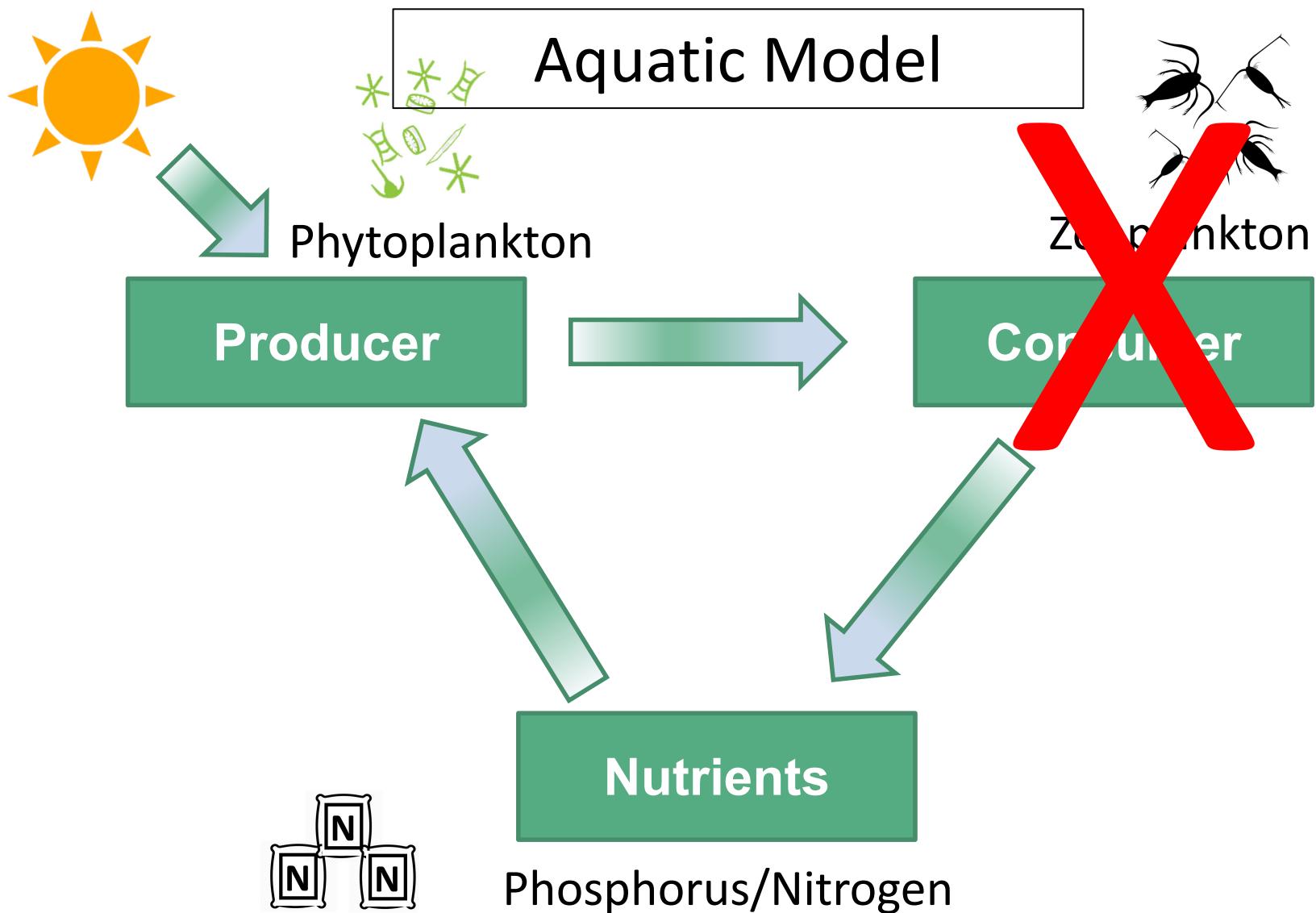
Image: Wikimedia commons

All these factors interact to control primary productivity; you can choose in the module what drivers to include in the model!

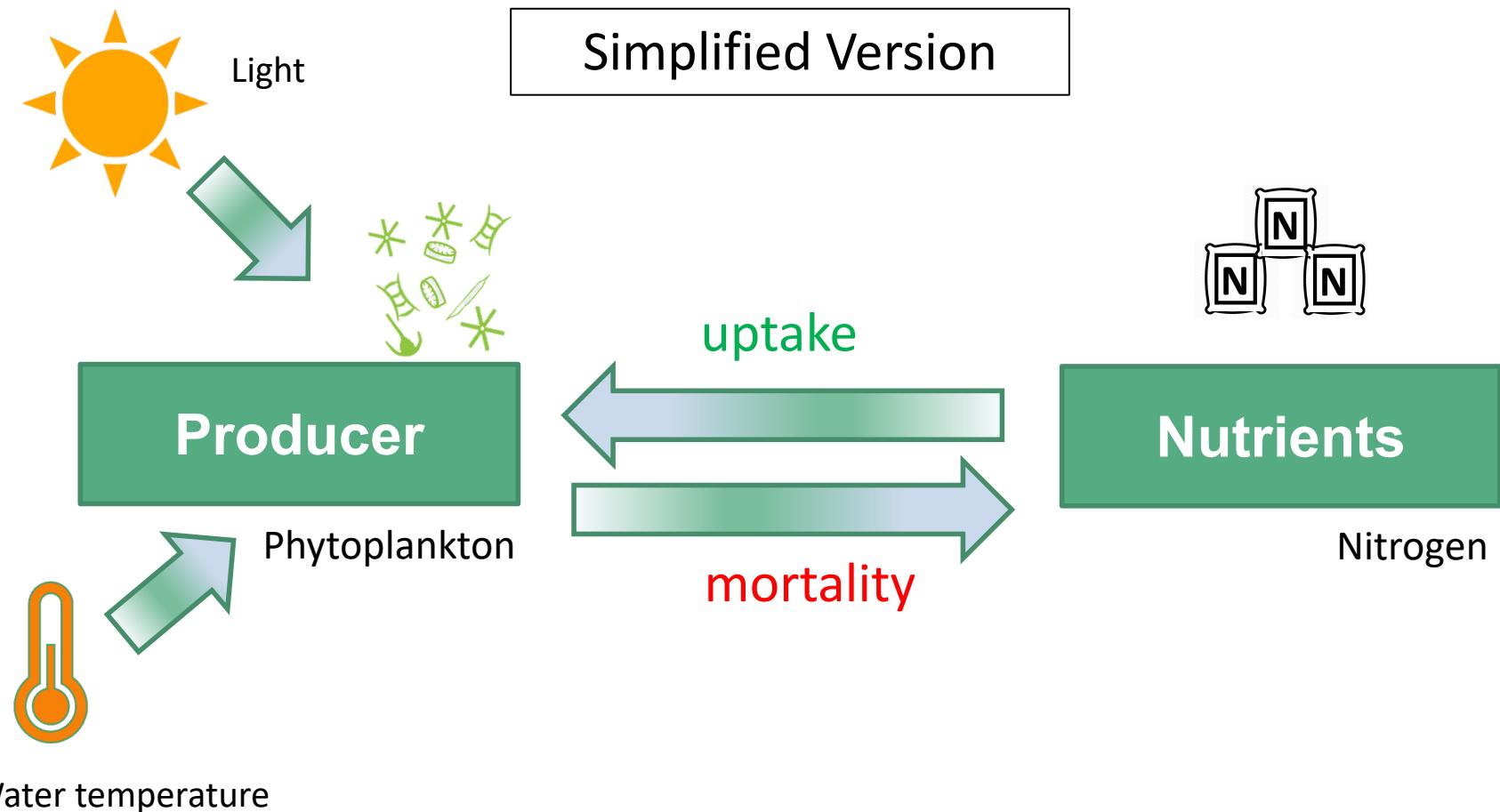
# Primary Productivity Model



# Primary Productivity Model



# Primary Productivity Model



# National Ecological Observatory Network (NEON)

- We will be forecasting productivity at NEON sites
- NEON is a continental-scale observatory designed to collect long-term open access ecological data to better understand how U.S. terrestrial and aquatic ecosystems are changing

NEON.D03.BARC.DP1.20002 - NetCam SC IR - Thu Dec 31 2020 20:00:05 UTC  
Camera Temperature: 49.5  
Exposure: 44

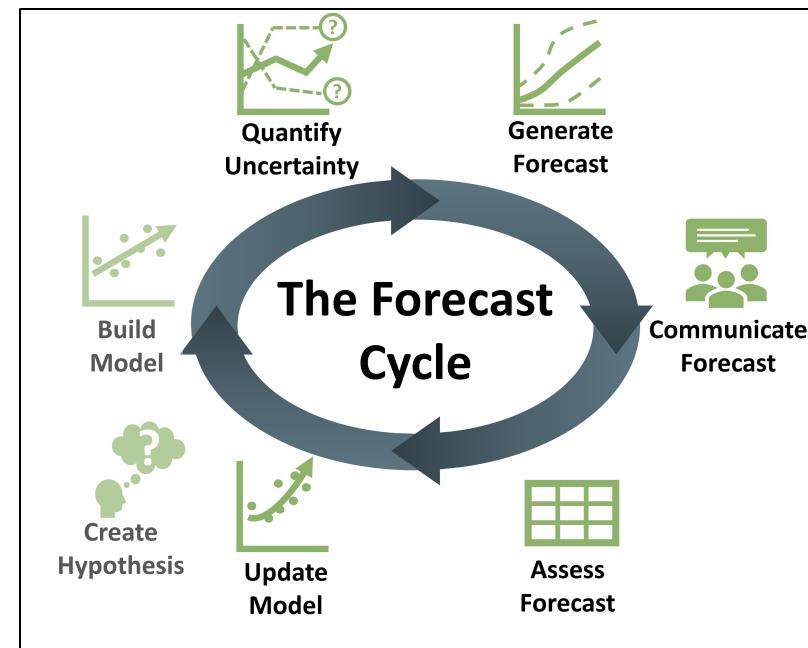


Image: Phenocam



# Learning objectives of today's module:

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

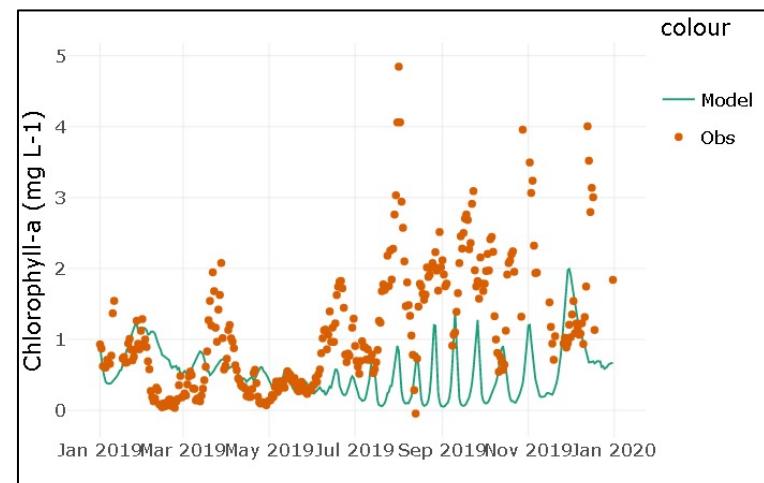
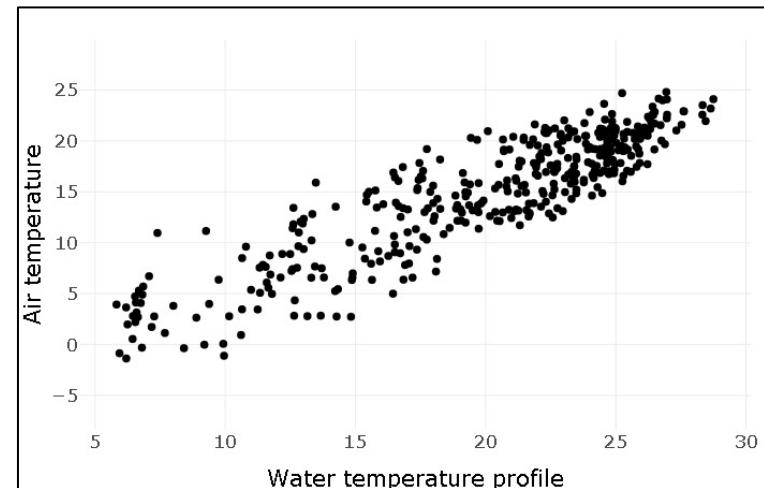


# Activity A



With a partner (work in pairs):

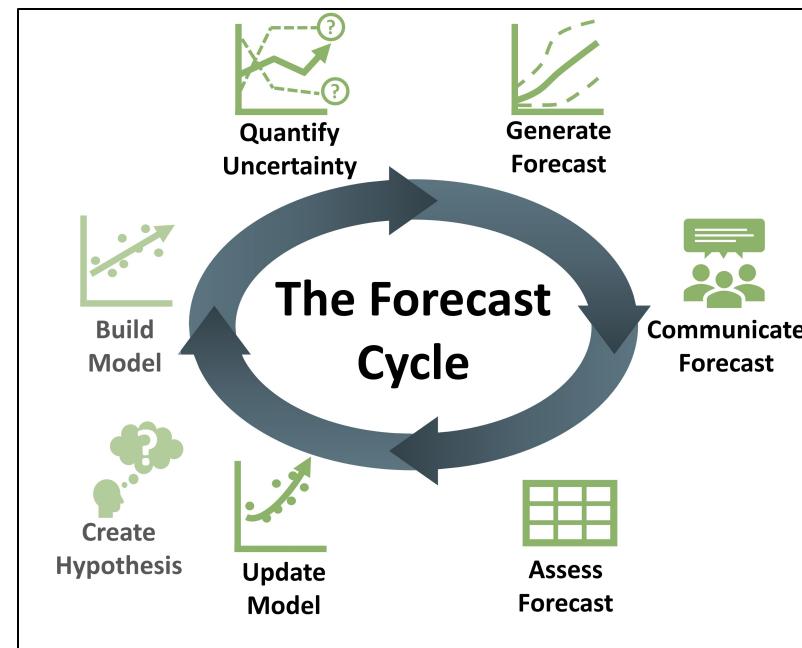
1. Select a NEON site
2. Visualize the variables at the site
3. Explore variable relationships
4. Within pairs, each builds their own ecosystem model for their lake and compares the performance of the two different models in predicting productivity at the same site



# Activity B

With a partner (work in pairs):

1. Quantify forecast uncertainty
2. Generate a forecast of primary productivity for your site
3. Communicate forecast
4. Assess forecast with data
5. Update model to improve forecast
6. Generate the next forecast



# Activity C

With a partner (work in pairs):

1. Apply their ecological model to a second NEON site
2. Generate ecological forecasts for this second site using their initial productivity model
3. Work together in a group to present the results from their two sites and two different models and discuss why the forecasts are similar or different among the different sites and models



# Shiny App

- The module can be accessed at:  
<https://macrosystemseddie.shinyapps.io/module5/>
- This is an interactive webpage built using R
- It has interactive plots and options embedded which allow you to build your own personal model, visualize and explore the data, and answer questions



Module 5: Introduction to Ecological Forecasting

Module Overview    Introduction    Exploration    Activity A    Activity B    Activity C

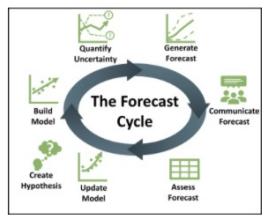
 eddie  
environmental data-driven inquiry & exploration

## Introduction to Ecological Forecasting

### Summary

Ecological forecasting is a tool that can be used for understanding and predicting changes in populations, communities, and ecosystems. 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 forecasters develop and update forecasts using the iterative forecasting cycle, in which they make a hypothesis of how an ecological system works, embed their hypothesis in a model, and use the model to make a forecast of future conditions. When observations become available, they can assess the accuracy of their forecast, which indicates if their hypothesis is supported or needs to be updated before the next forecast is generated.

In this module, students will apply the iterative forecasting cycle to develop an ecological forecast for a National Ecological Observation Network (NEON) site. Students will use NEON data to build an ecological model that predicts primary productivity. Using their calibrated model, they will learn about the different components of a forecast with uncertainty and compare productivity forecasts among NEON sites.



The diagram illustrates the iterative forecasting cycle as a circular process. The central circle is labeled "The Forecast Cycle". Surrounding this center are six rectangular boxes, each containing an icon and a label: "Build Model" (with a bar chart icon), "Create Hypothesis" (with a tree icon), "Assess Forecast" (with a grid icon), "Update Model" (with a line graph icon), "Generate Forecast" (with a scatter plot icon), and "Quantify Uncertainty" (with a bell curve icon). Arrows indicate a clockwise flow between these steps.

# Let's Go!

- For the activity we will work in pairs.
- Each pair selects the same NEON site and works through the Activities A & B
- We will breakout into rooms of four students
- Today's goal is to finish Activity A
- Next class we will continue on with Activity B & C

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

# Saving & Resuming Progress

1. Navigate to the “Introduction” tab
2. Scroll down to “Save your progress” section
3. Click on the “Download user input” button. A ‘.rds’ file will download
4. Store this file somewhere safe on your computer
5. When continuing, you will upload this file and it will populate your answers and saved parameters

Save your progress

If you run out of time to finish all the activities you can save your progress and return to it at a later date. Click the 'Download' button below and a file 'module5\_answers\_ID\_number.rds' will download. Store this file in a safe place locally on your computer.

 Download user input

Resume your progress

To reload the app input you can upload the downloaded '.rds' file below and it will populate your answers into the Shiny app.

**Upload data**

No file selected

# Downloading the Report

1. Navigate to the “Introduction” tab
2. Scroll down to “Save your progress” section
3. Click on the “Generate Report (.docx)” button.
4. Then the “Download Report” button will appear. Click this to download the report with answer and plots embedded within a Word document.

**Generate Report**

This will take the answers you have input into this app and generate a Microsoft Word document (.docx) document with your answers which you can download and make further edits before submitting. Return here when you have completed the module.

 Generate Report (.docx)

 Download Report

**Questions still to be completed:**

- Activity A: Objective 5 - Q. 15 Save plot of model run
- Activity B: Objective 9 - Q. 21
- Activity B: Objective 10 - Q. 22
- Activity B: Objective 11 - Q. 23 Save plot of new ecological forecast

# Thank you for participating!

NEON.D09.PRPO.DP1.20002 - NetCam SC IR - Mon Nov 30 2020 23:15:06 UTC  
Camera Temperature: 25.5  
Exposure: 2400



Stay tuned for future modules:

- **Uncertainty** – Module 6
- **Model-Data Fusion** – Module 7
- **Decision Making** – Module 8

Find out more at:

[macrosystemsEDDIE.org](https://macrosystemsEDDIE.org)

# Macrosystems EDDIE: Introduction to Ecological Forecasting continued...

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Macrosystems EDDIE Module 5, Version 1.

<http://module5.macrosystemseddie.org>

Module development supported by NSF DEB-1926050; NSF DBI-1933016

# Round 2 – Activity B

From last weeks class and homework you should have:

- A saved “module5\_answers\_123456.rds” file from the Shiny app

## Today

- Reload progress using the ‘.rds’ file into the app
- When the activity is completed, present your results to the other group in your breakout room and compare the differences
- Reconvene in the main room and ask for a couple of people to present their answers back to the group

# Assignment

- Complete Q 1-24 and submit on Canvas by 11am on Thursday
- If you were unable to save your progress using the ‘.rds’ file or are using the Word document to input your answers you can quickstart:

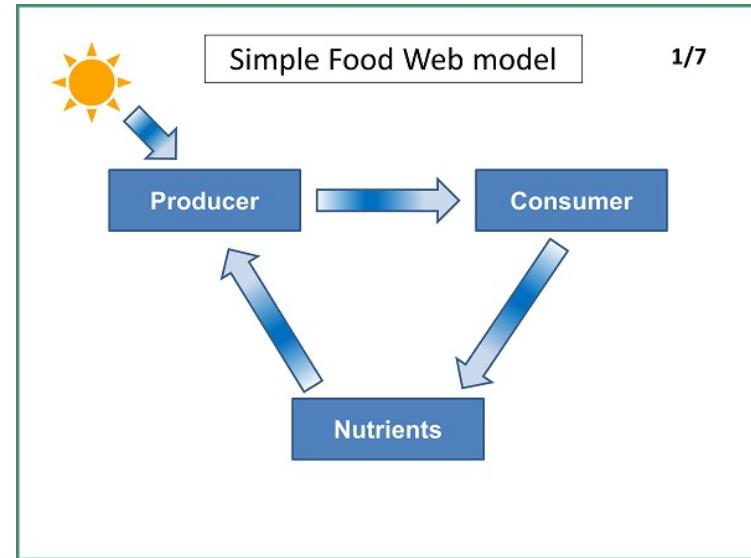
## Quickstart:

1. Select a site on Activity A Objective 1
2. Navigate to Objective 5
  - a. Check the temperature box
  - b. Update the sliders to your answers from Q15
  - c. Run the model, add the observations and save the plot

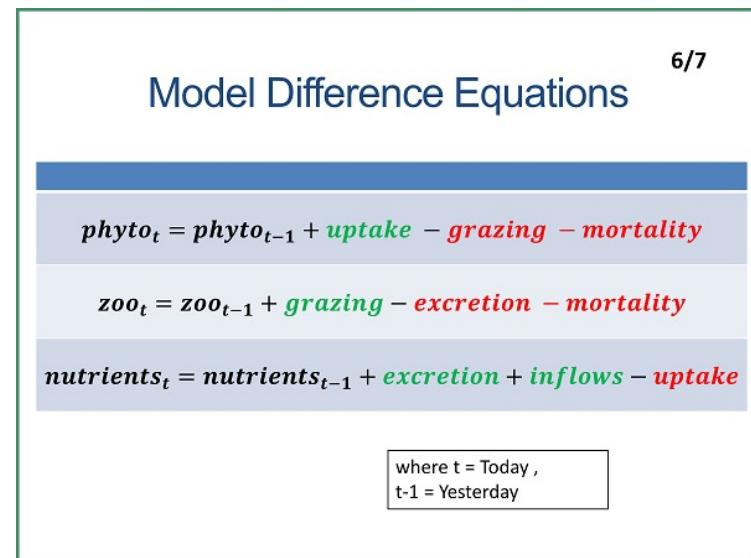
# Models

## Primary Production in Lakes

### Conceptual Model

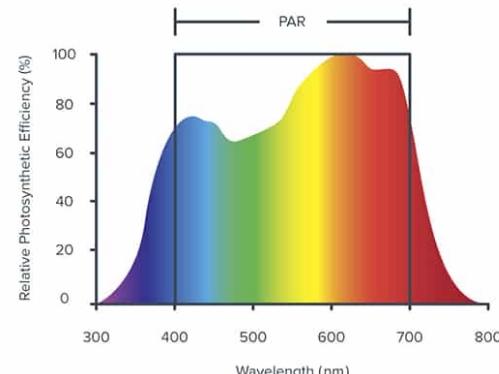


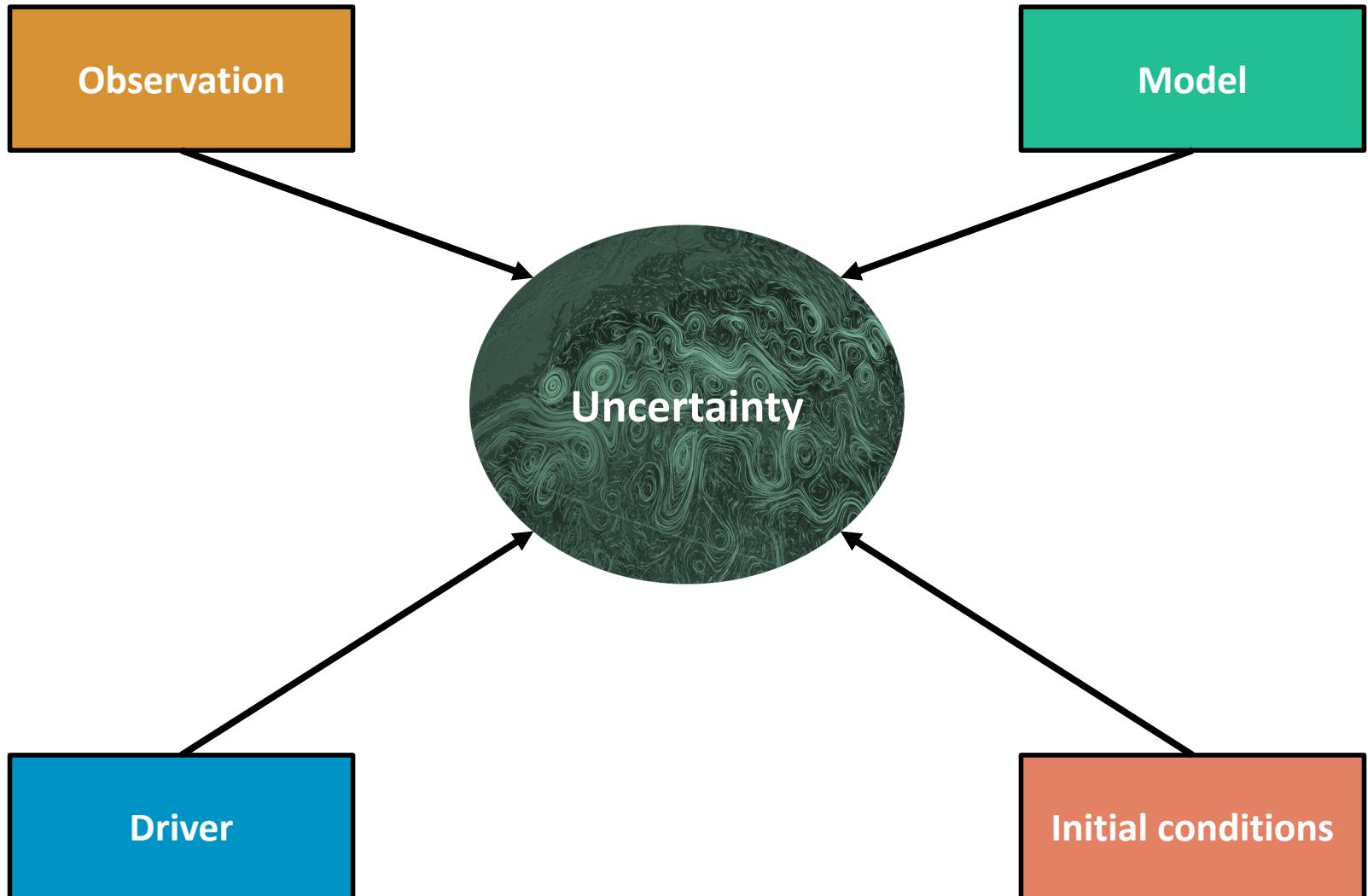
### Mathematical Model



# Model Components

- **Phytoplankton** – are photosynthetic producers which convert energy into organic substance
- **Zooplankton** – are secondary consumers and graze on microscopic algae like phytoplankton
- **Nutrients** – in the water column are taken up by phytoplankton and converted to organic substances in the presence of sunlight
- **Photosynthetic Active Radiation (PAR)** – is the spectral range of solar radiation from 400 to 700 nm that photosynthetic organisms use in the process of photosynthesis





# Ecological Forecast Examples

1. Short-term forecasts of phenological events in plants and pest insects.
2. Short-term forecasts of reservoir water quality for management of drinking water supply
3. Optimizing sustainable harvests of target fish while minimizing bycatch
4. Risk of encountering Atlantic Sturgeon in Chesapeake Bay

See Shiny app for more info...

The image displays three separate web pages illustrating different types of ecological forecasts:

- USA-NPN (National Phenology Network):** This page shows a detailed forecast for an emerald ash borer, featuring a close-up photograph of the insect and a map indicating its predicted movement across the United States.
- FLARE (Forecasting Lake And Reservoir Ecosystems):** This page features a large, scenic photograph of a lake surrounded by autumn foliage, with the word "Forecasts" overlaid in white text.
- NOAA COASTWATCH WEST COAST REGIONAL NODE EcoCast:** This page is specifically focused on the risk of encountering Atlantic Sturgeon. It includes a large image of a sturgeon, a map of the Delaware River and surrounding areas, and a legend defining risk levels (Low Risk = Yellow, Medium Risk = Orange, High Risk = Red).

What do you think are the key components of a forecast?

Data

Knowledge

Forecast

Uncertainty

Communication

# Ecological forecasting helps to understand macrosystems ecological interactions

- Ecological forecasting can be used to test our understanding of ecosystem function
- It can also inform the design of data collection at certain spatial and temporal scales
- Macrosystems ecologists study ecological dynamics and feedbacks at multiple interacting spatial and temporal scales

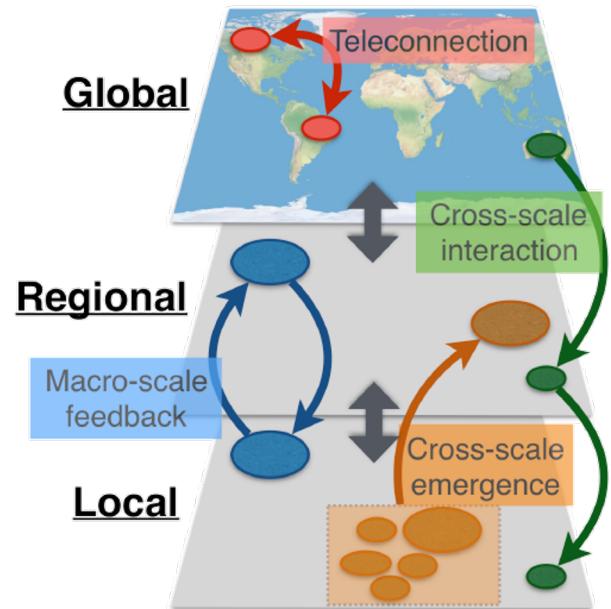
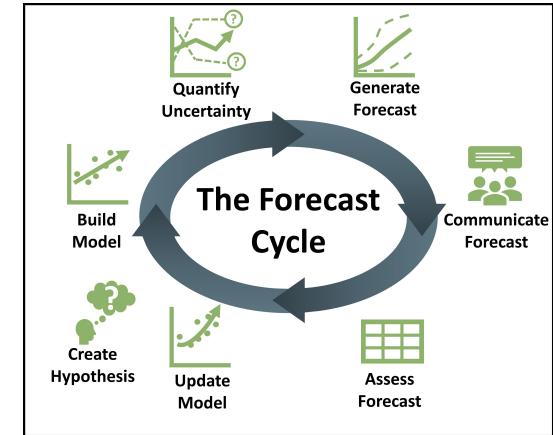


Figure modified from: Heffernan et al. 2014

# Quantifying Uncertainty

- Analyzing the sources of uncertainty can inform which measurements are critical to reduce uncertainty
- Quantifying uncertainty can include:
  1. Historical performance of models
  2. Known variability in natural processes
  3. Analysis of the data which is used to generate the forecast