Macrosystems EDDIE:
Introduction to Ecological Forecasting

Moore, T. N., Carey, C.C., Thomas, R. Q. 23 January 2021.

Macrosystems EDDIE: Introduction to Ecological Forecasting.

Macrosystems EDDIE Module 5, Version 1.

http://module5.macrosystemseddie.org

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

Macrosystems EDDIE

Environmental Data-Driven Inquiry & Exploration in Macrosystems Ecology

NSF | neon Operated by Battelle

SERC the Science Education Resource Center at Carleton College

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

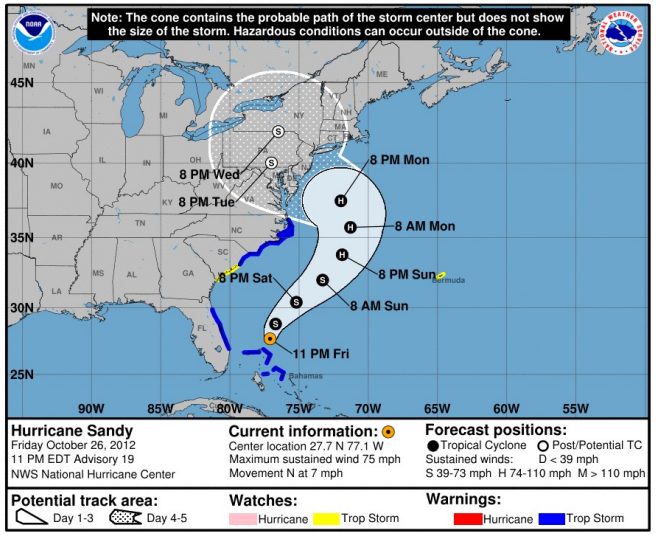
Before we start

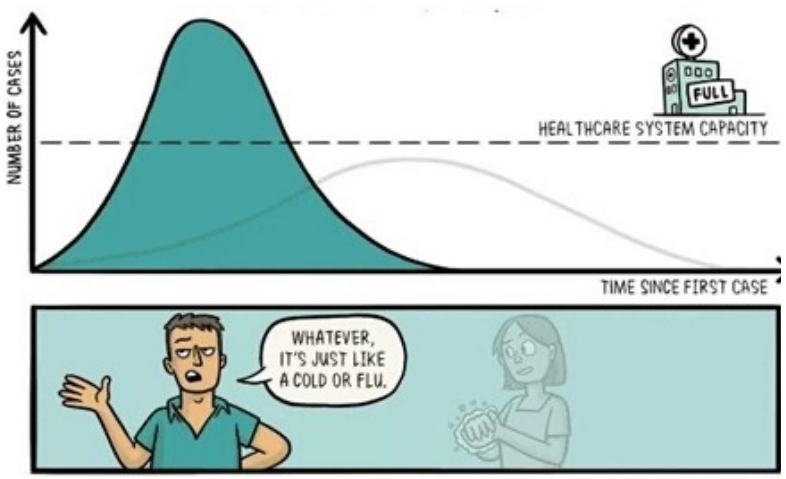
What do we Forecast?

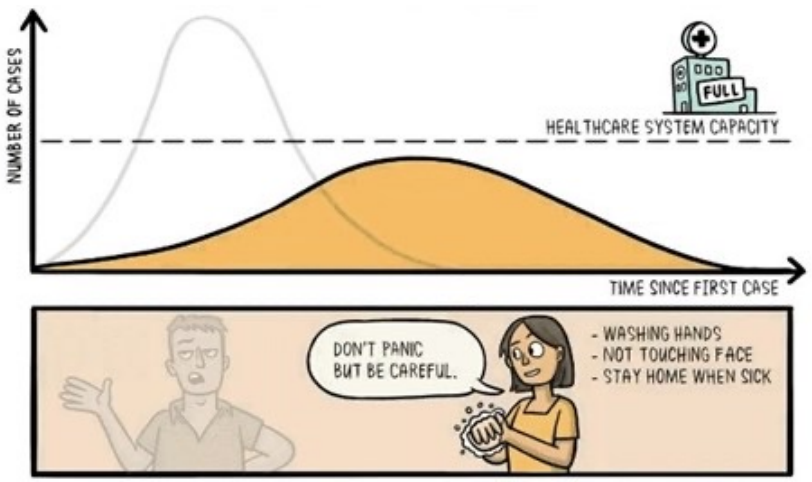
- Weather
- Floods
- Hurricanes
- Forest fires
- Economy
- Disease transmission
- Election results
- Greenhouse gas emissions
- Earthquakes
- Land use
- Player and team performance in sports
- Sales
- Transport planning
- and much more!

What is the purpose of a forecast?

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







@SIOUXSIEW @XTOTL @THESPINOFFTV

"ADAPTED FROM THOMAS SPLETTSTOßER (@SPLETTE) AN

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"ADAPTED FROM THOMAS SPLETTSTOßER (@SPLETTE) AND THE CDC"

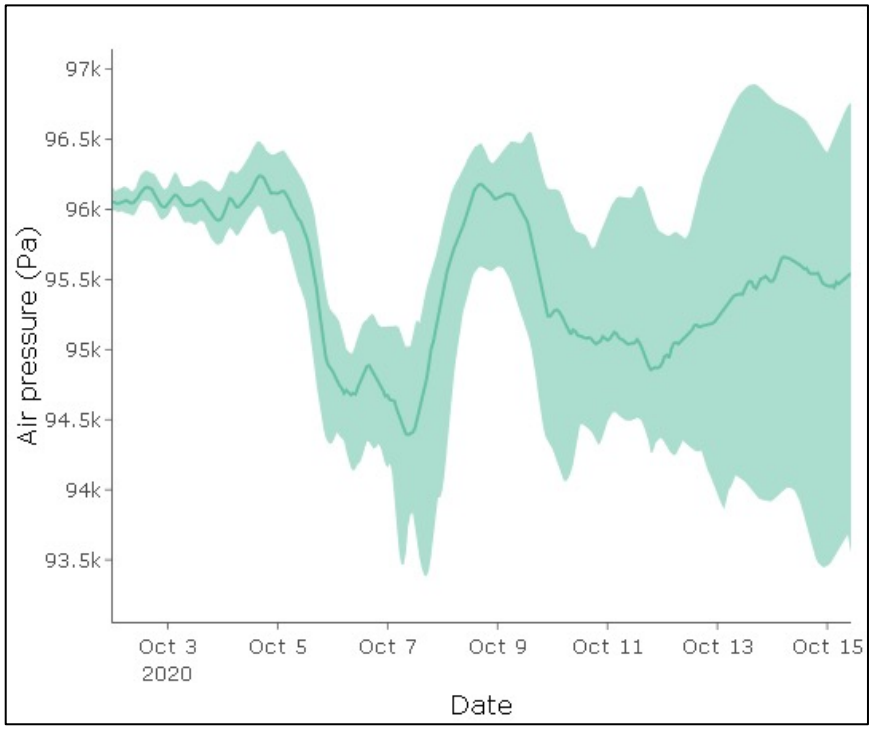
Our focal question:

What is an Ecological Forecast?

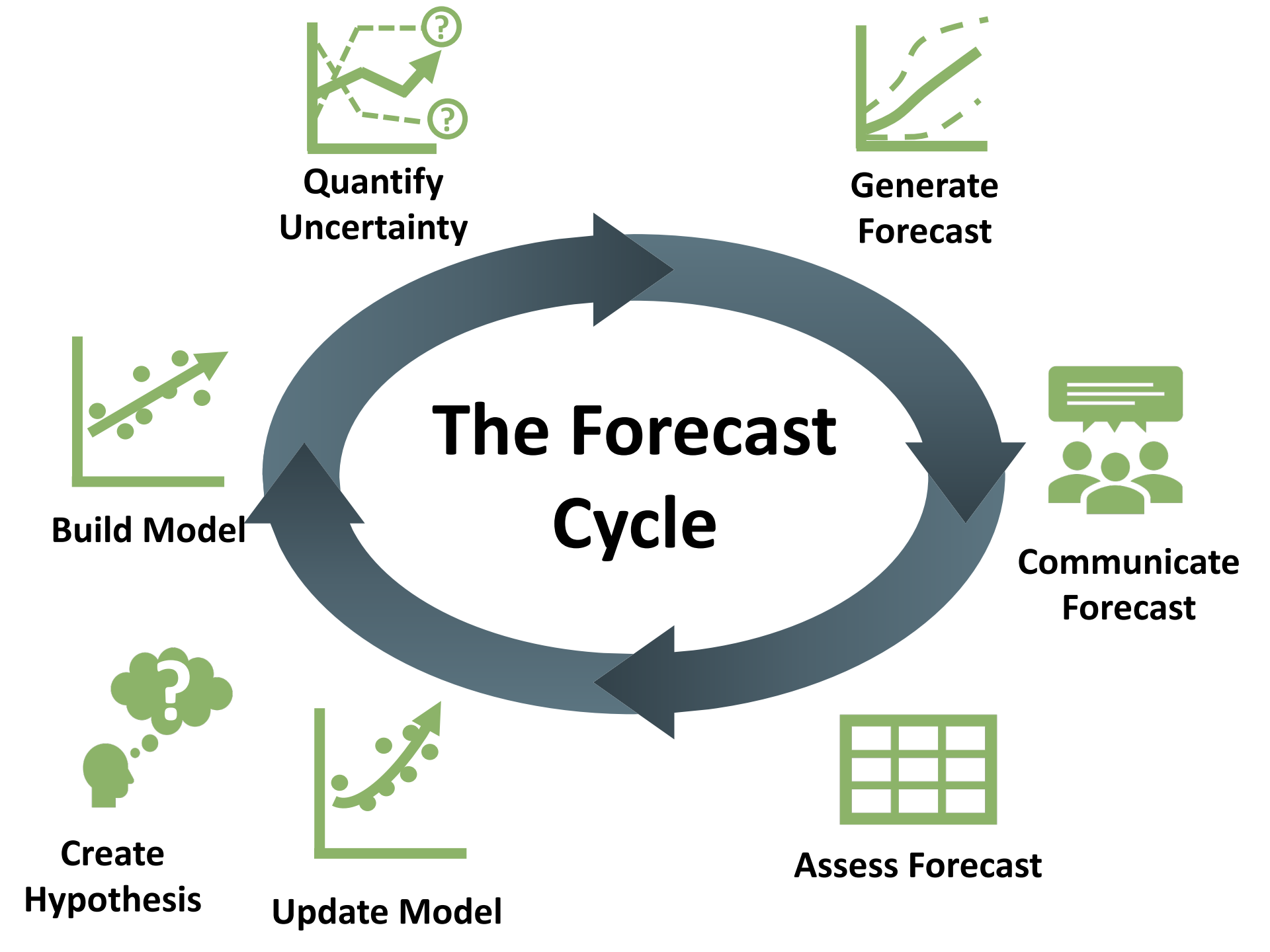
"Prediction of future environmental conditions with uncertainty"

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



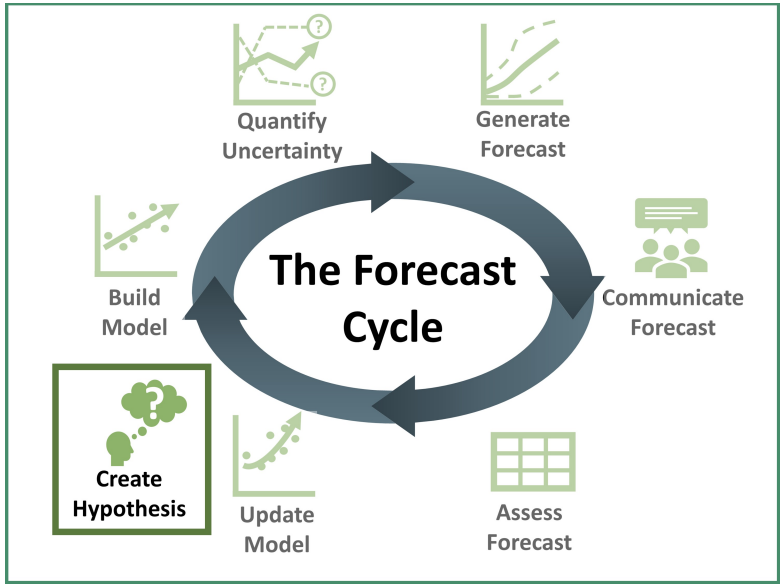
Plot showing 16 day forecast of air pressure with shaded regions showing 95% confidence interval and the solid line represents the median


Quantify Uncertainty
Generate Forecast
The Forecast Cycle
Build Model
Communicate Forecast
Create Hypothesis
Update Model
Assess Forecast

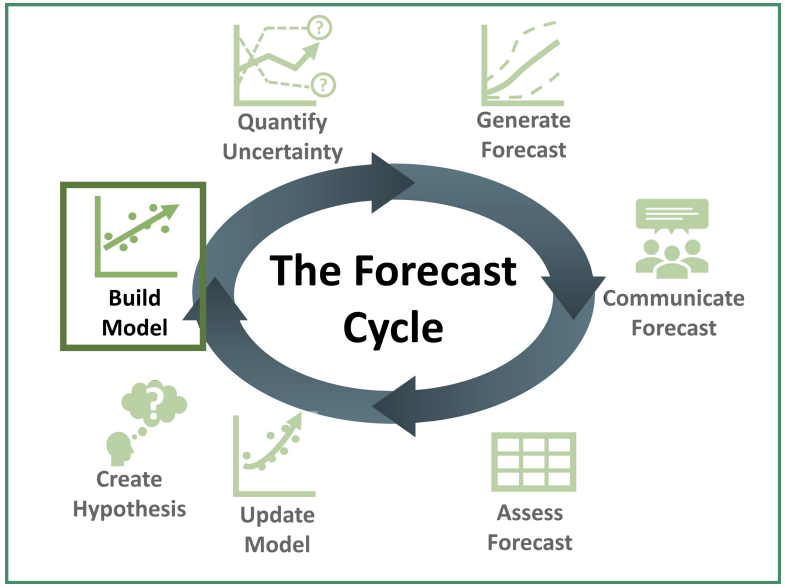
Create Hypothesis

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



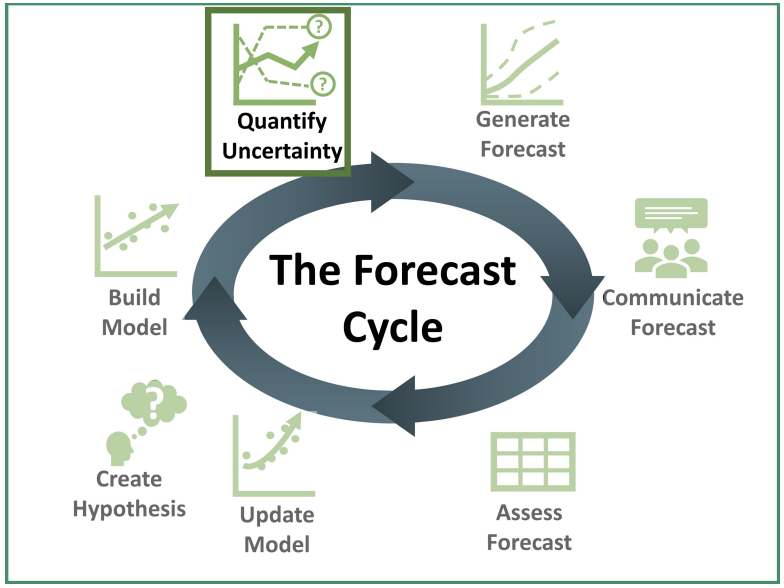
Using observational data, we can build a mathematical model to describe what is happening

E.g.,

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

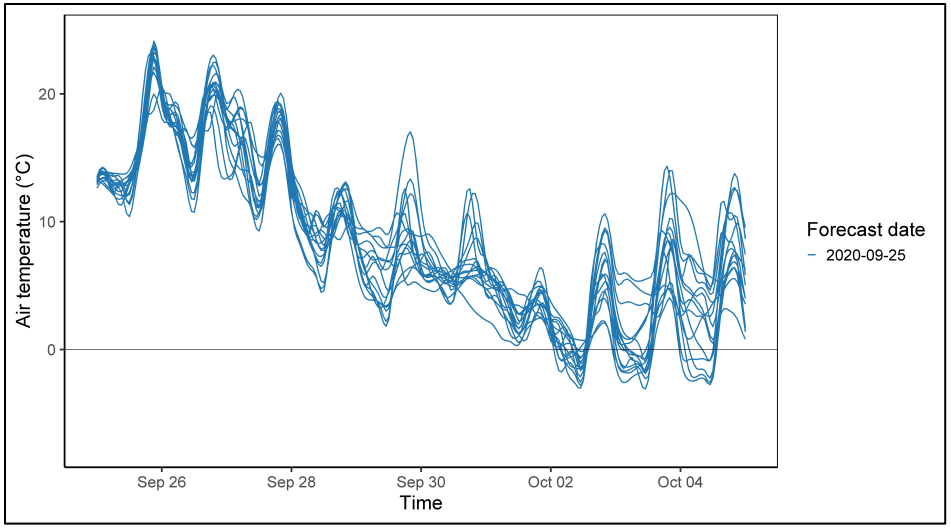
Amount of Phytoplankton today	Amount of Phytoplankton yesterday	Nutrient uptake	Phytoplankton death

Quantify Uncertainty



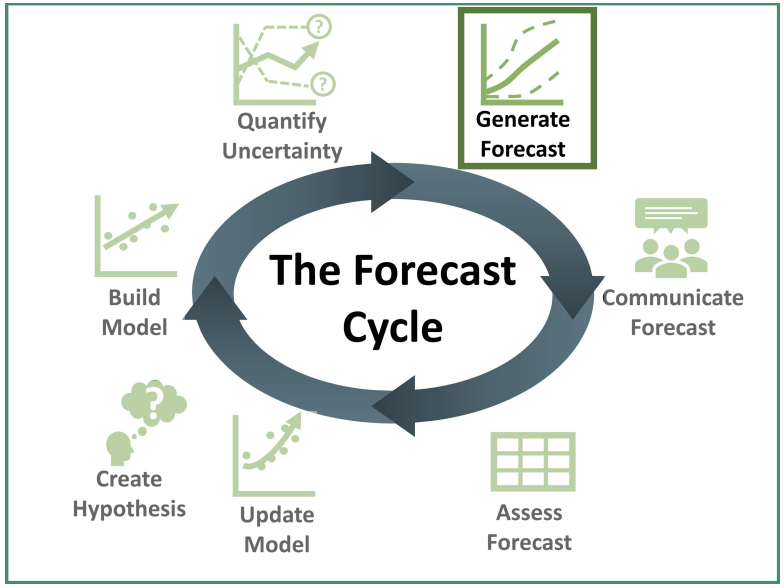
Characterization and reduction of the uncertainties in the forecast

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

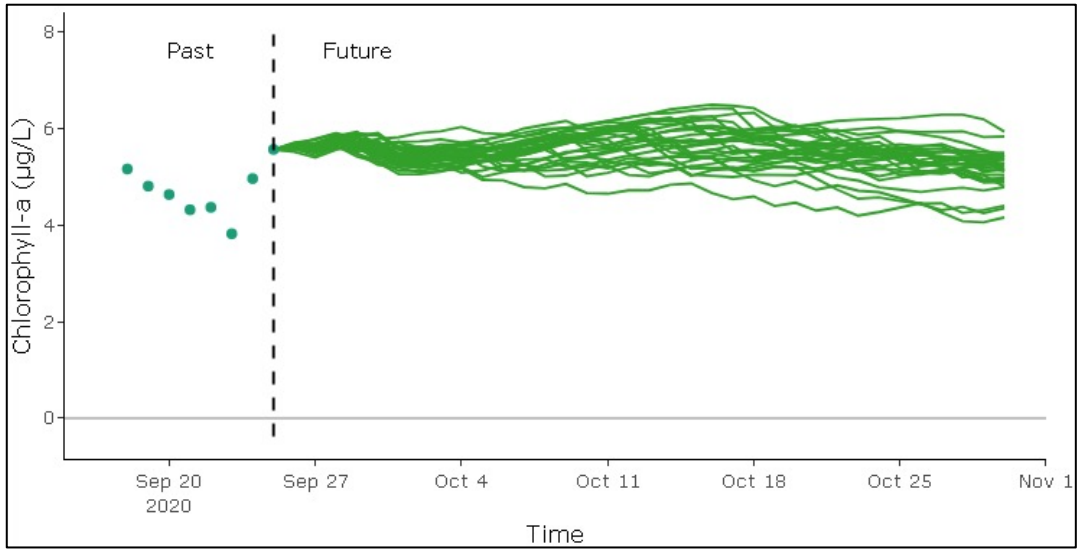


Plot showing 10 day forecast of air temperature with each line representing a different forecast (n = 15)

Generate Forecast

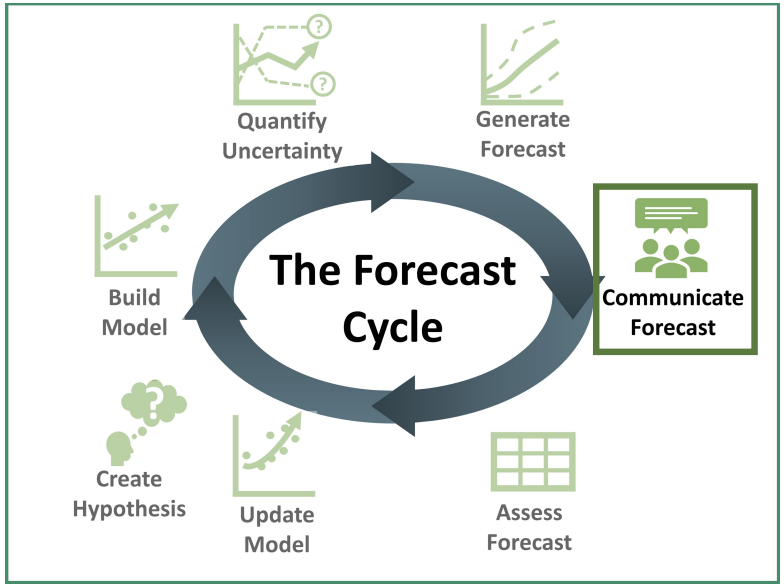


Generate a forecast into the future using the model that has been built and using forecasted driver data



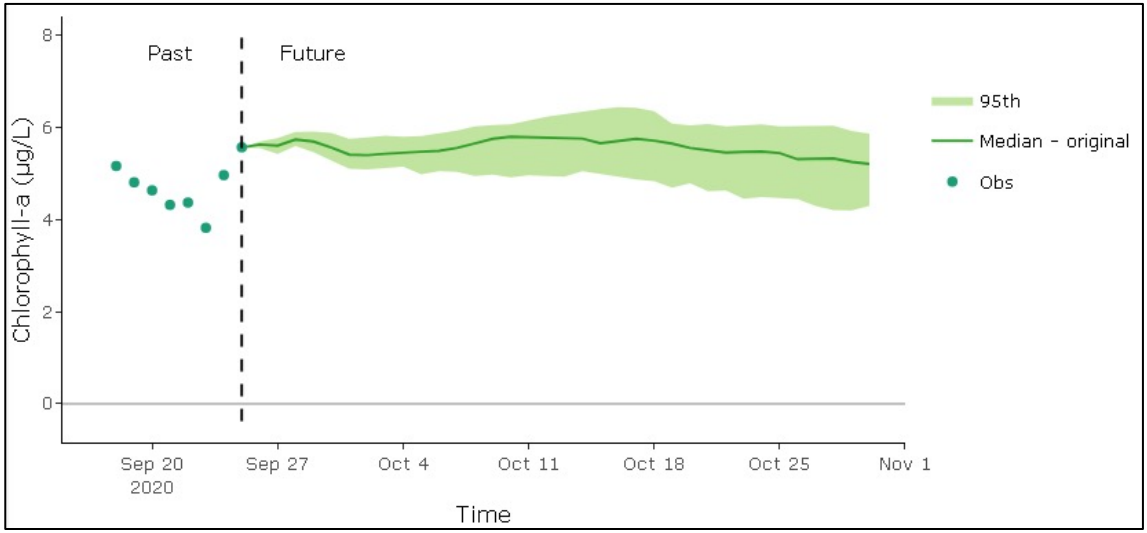
Plot showing 35 day forecast of primary productivity (chlorophyll-a) with each line representing a different forecast (n = 30)

Communicate Forecast



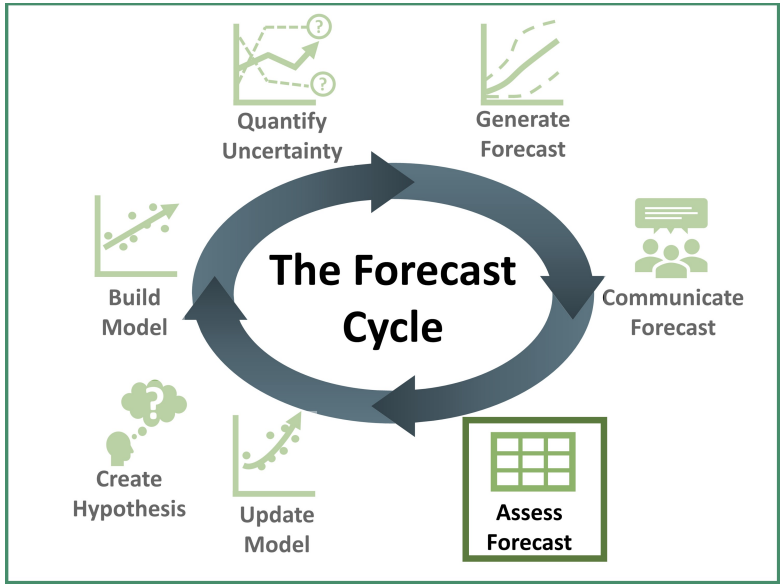
Communicate the forecast to stakeholders and potential end-users

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



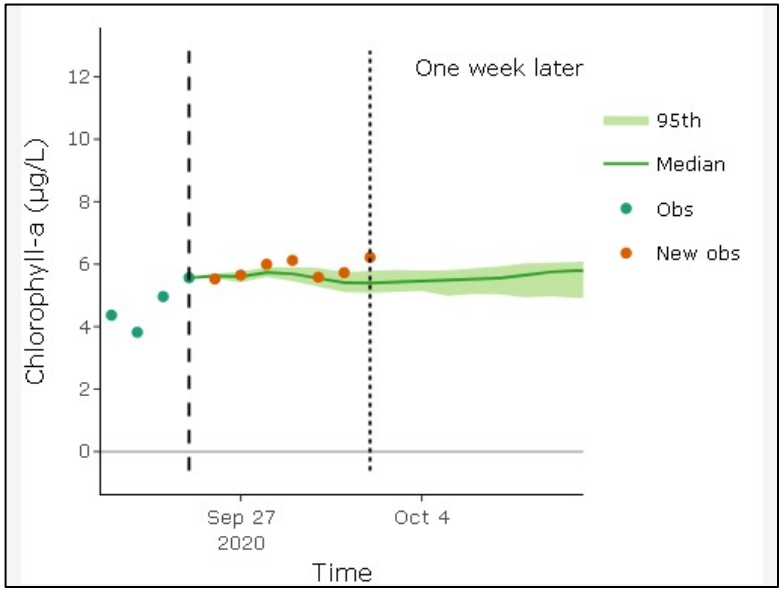
Plot showing 35 day forecast of primary productivity (chlorophyll-a) where the solid line represents the median and the shaded region is the 95% confidence interval (n = 30)

Assess Forecast



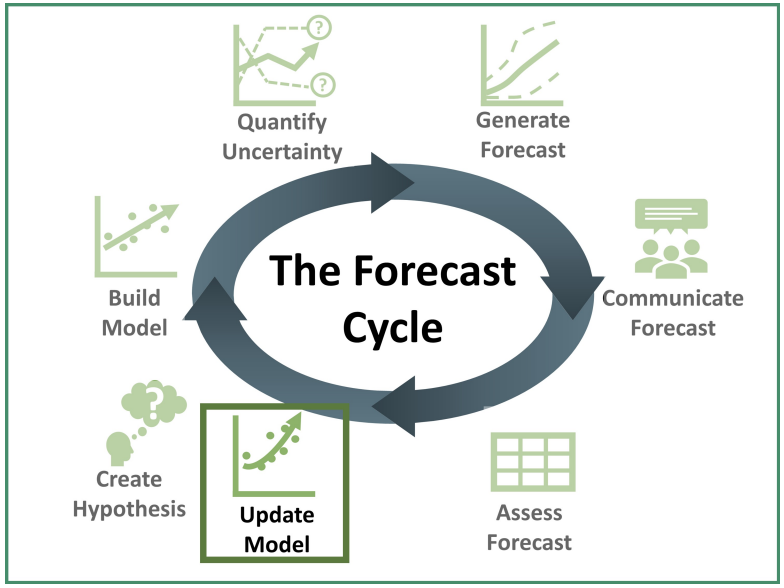
As time moves forward and new data are collected, the forecast can be compared to the data to see how well it performed

E.g., using statistical or visual measures



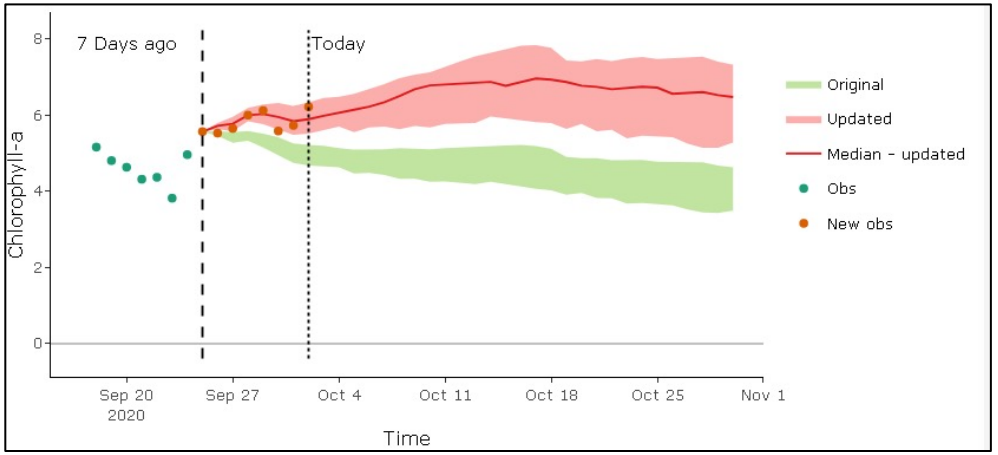
Plot showing the comparison of new observations (orange points) to the forecast of primary productivity (chlorophyll-a)

Update Model

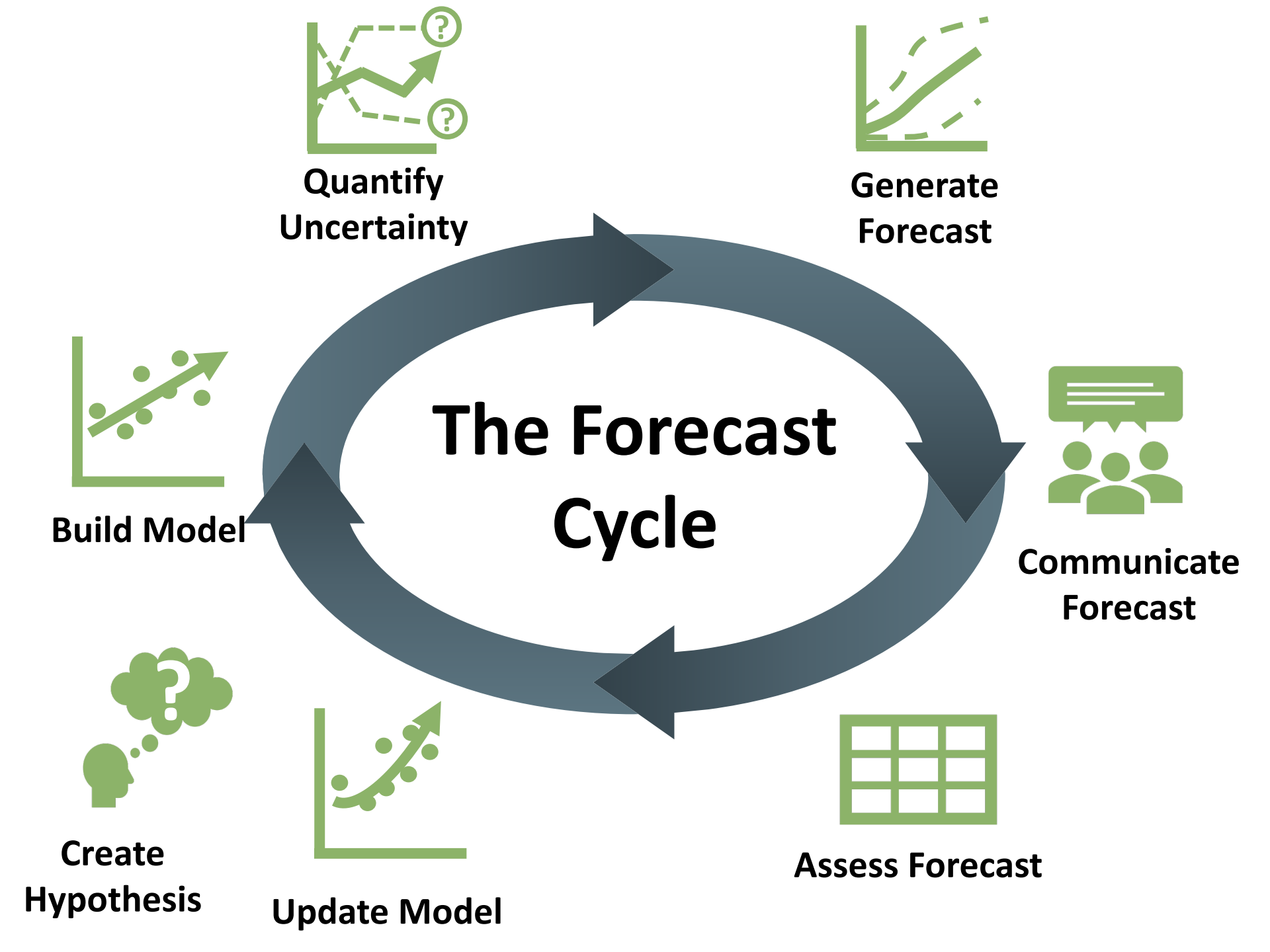


If the forecast did not perform well vs. observations, the model can be updated before generating a new forecast

E.g., updating the model parameters



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


Quantify Uncertainty
Generate Forecast
The Forecast Cycle
Build Model
Communicate Forecast
Create Hypothesis
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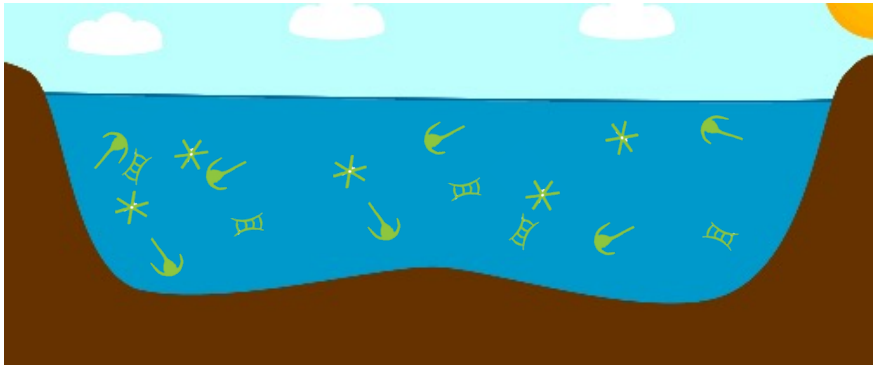
Assess Forecast

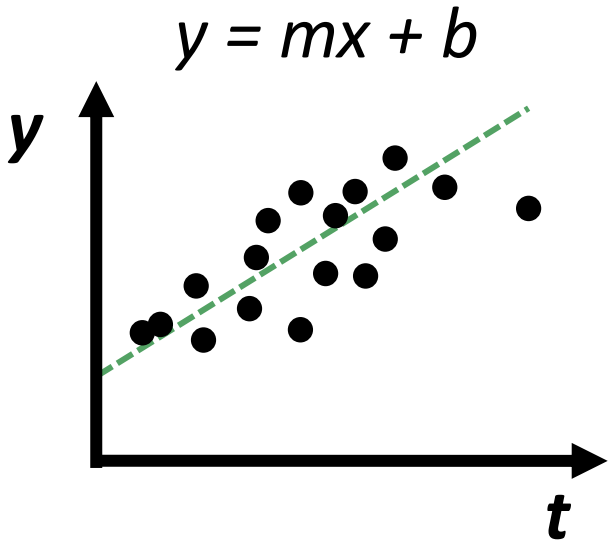
Today…

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





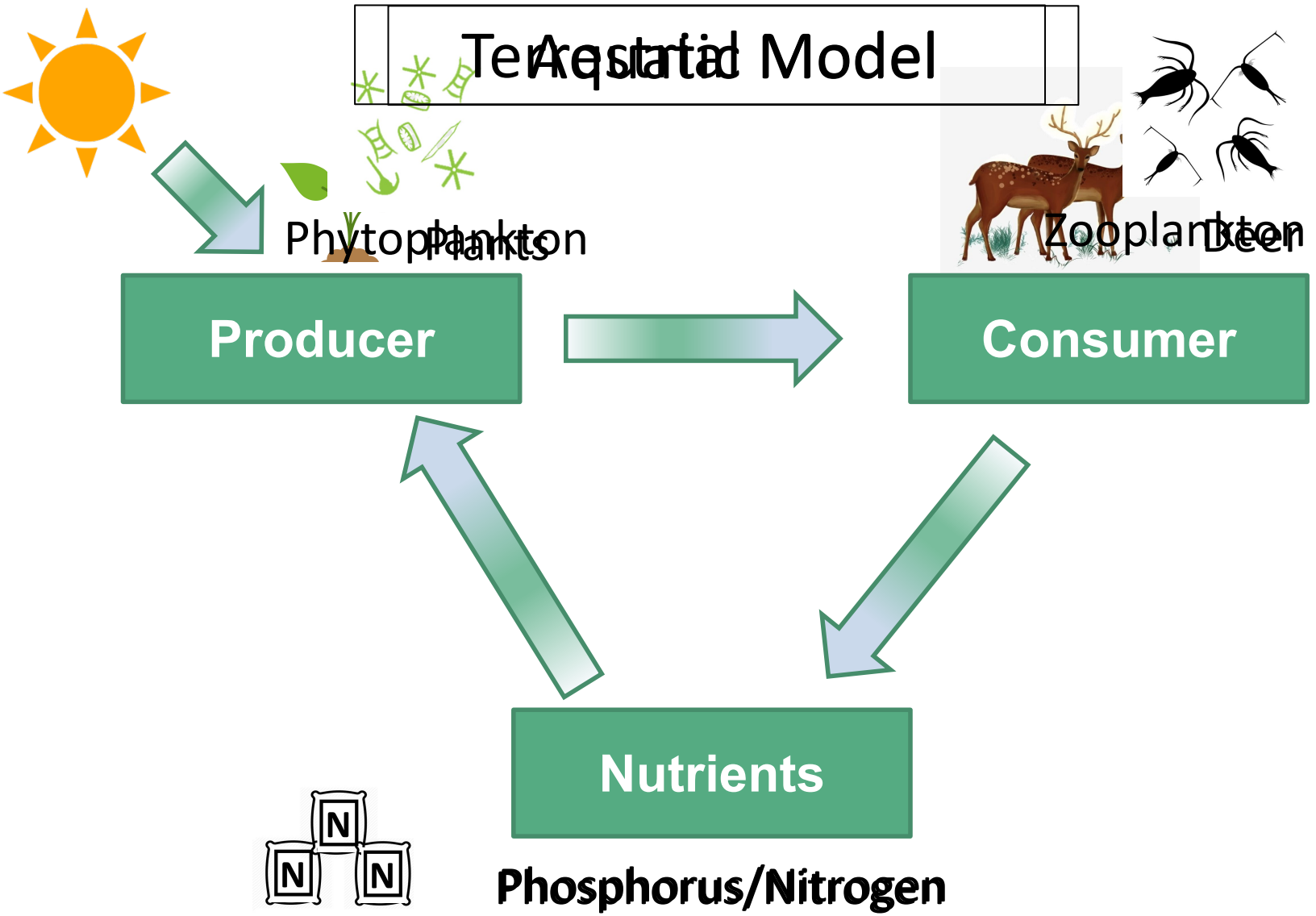
What are the drivers of primary productivity in a lake?

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

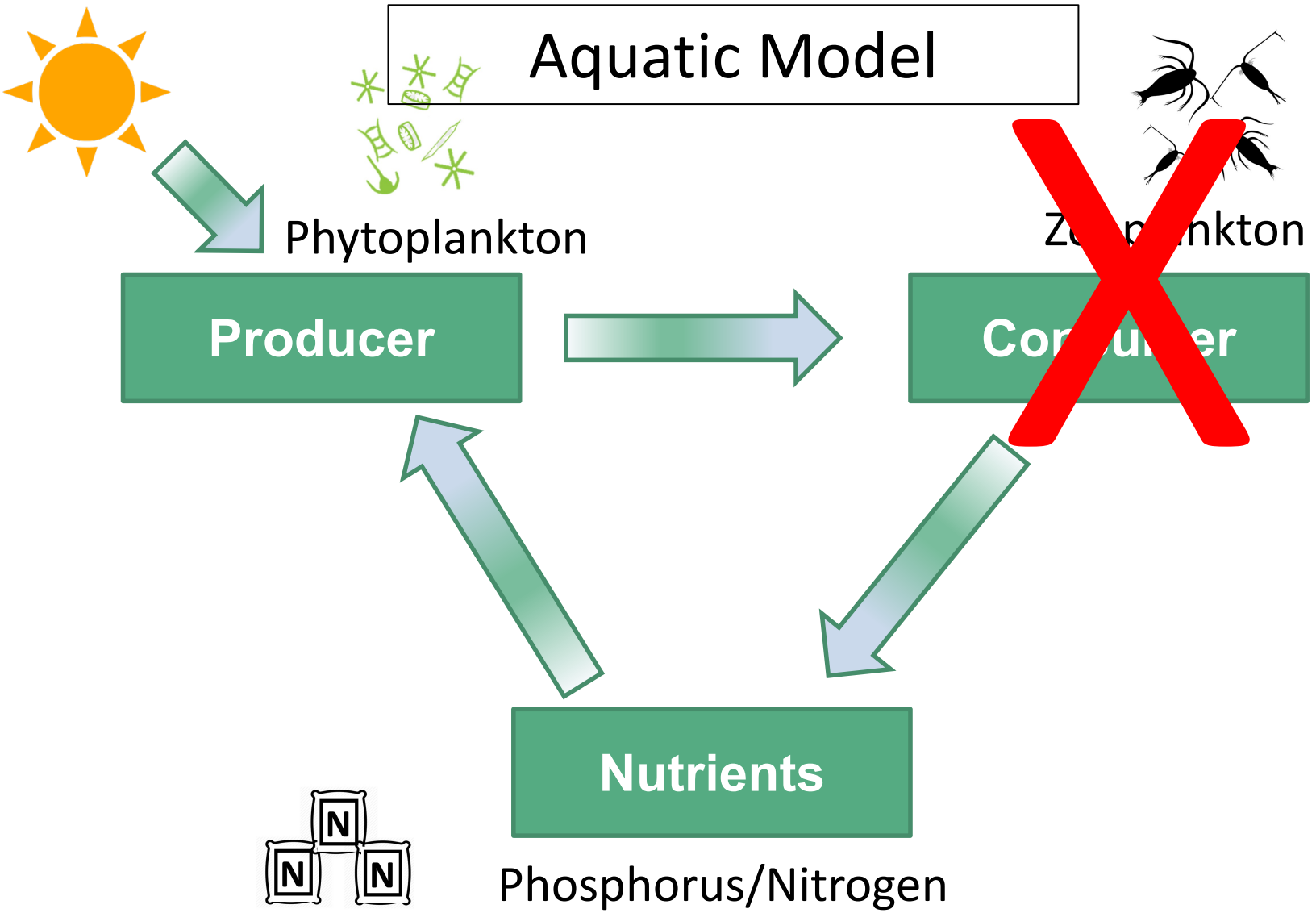
Image: Wikimedia commons

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

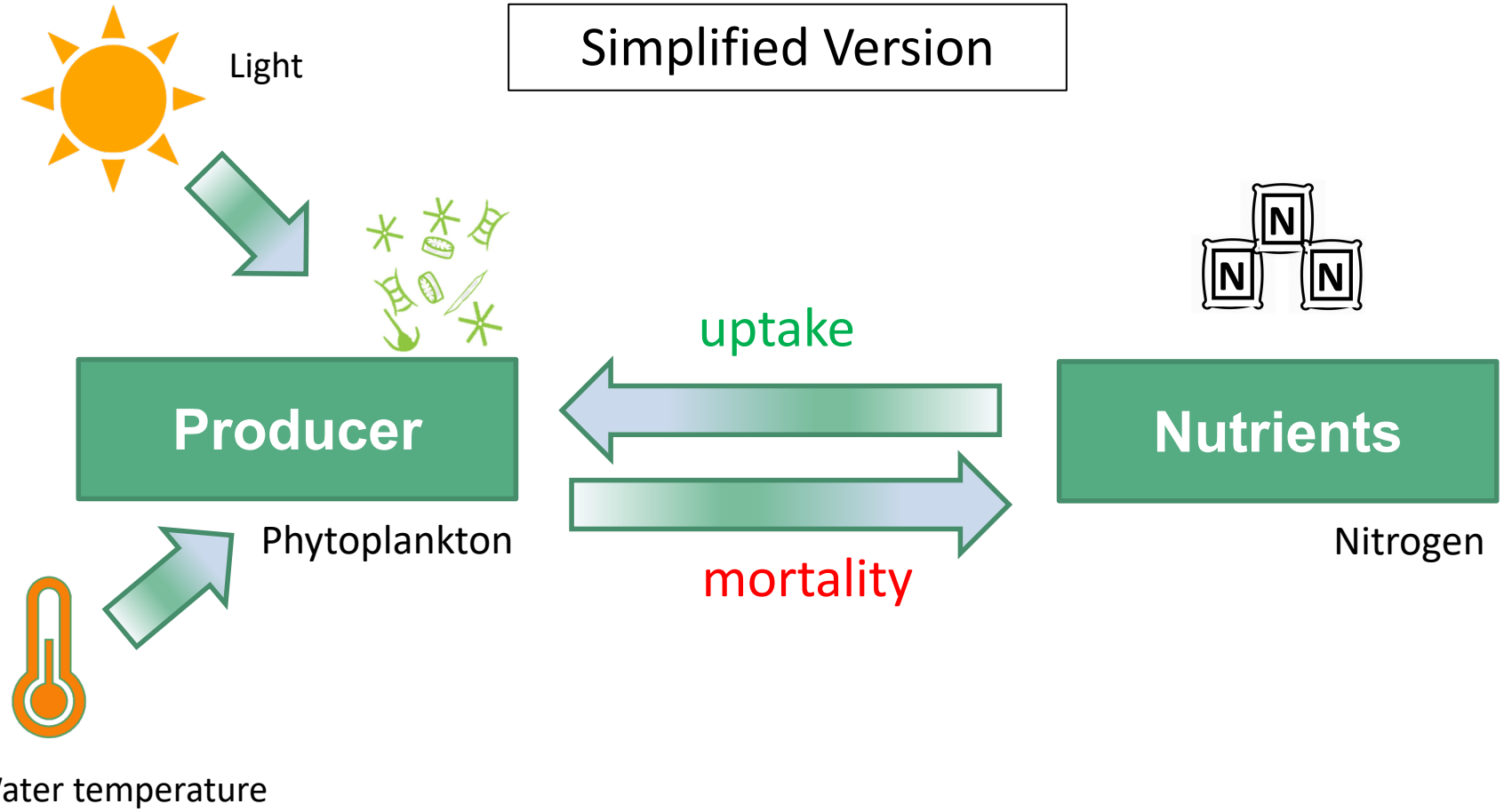
Primary Productivity Model



Primary Productivity Model



Primary Productivity Model



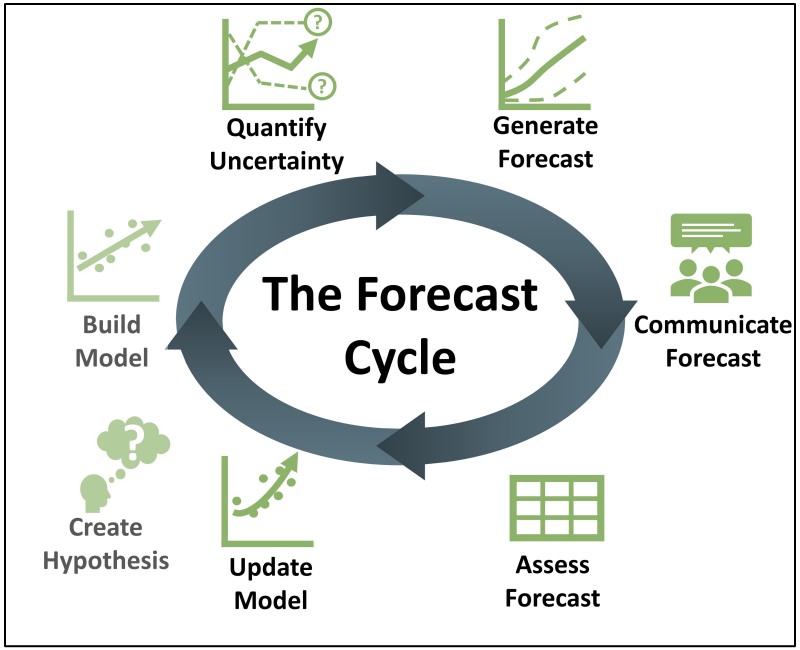
National Ecological Observatory Network (NEON)

- 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

Image: Phenocam

Learning objectives of today's module:

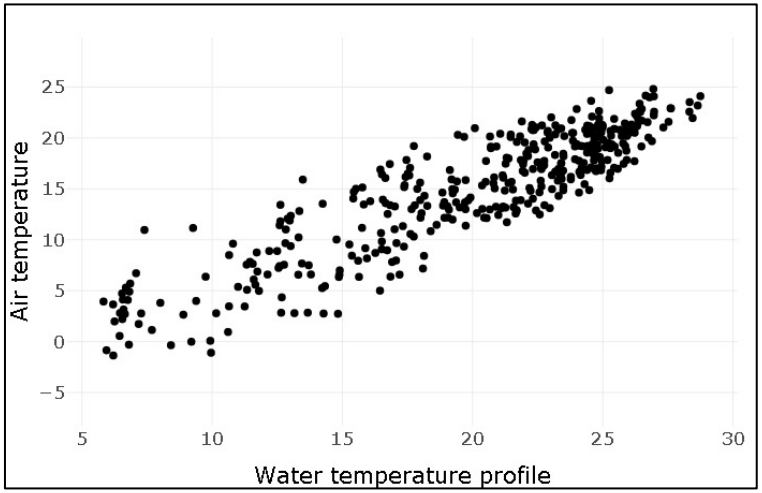
- Describe an ecological forecast and the iterative forecasting cycle
- Explore and visualize NEON data
- Construct an ecological model to generate forecasts of ecosystem primary productivity with uncertainty
- Adjust model parameters and inputs to study how they affect forecast performance relative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

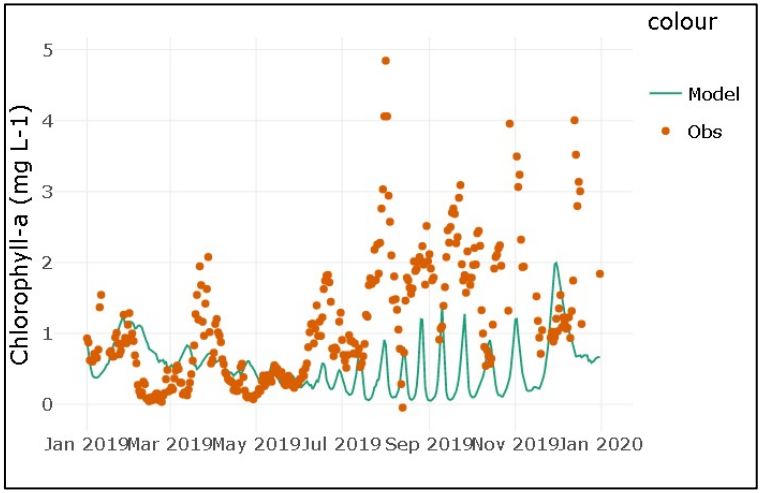


Activity A

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

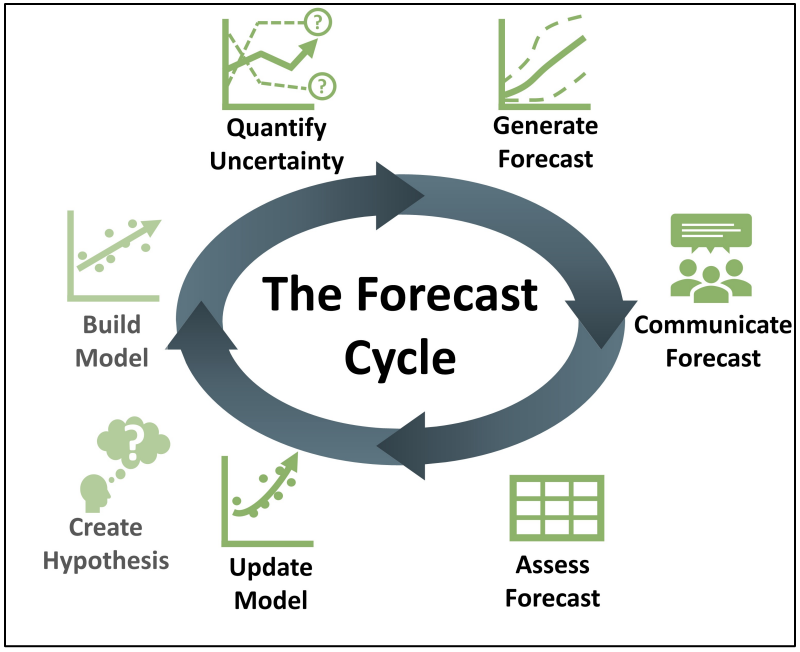




Activity B

With a partner (work in pairs):

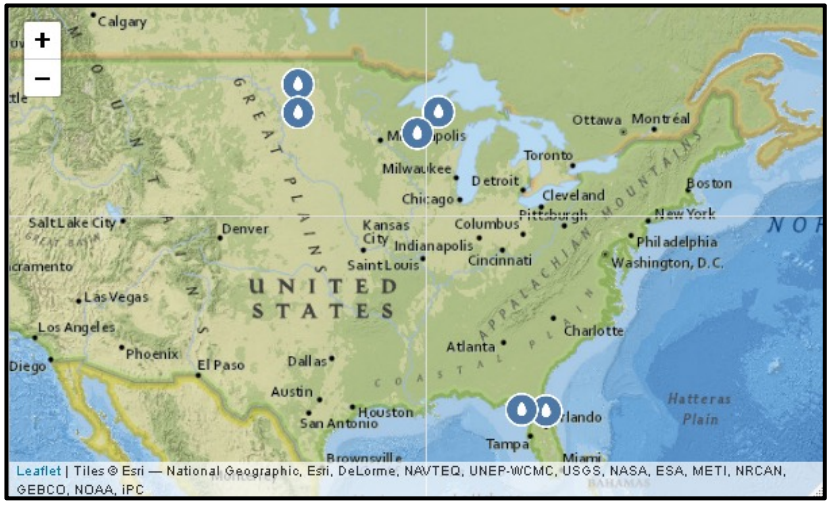
1. Quantify forecast uncertainty
2. Generate a forecast of primary productivity for your site
3. Communicate forecast
4. Assess forecast with data
5. Update model to improve forecast
6. Generate the next forecast



Activity C

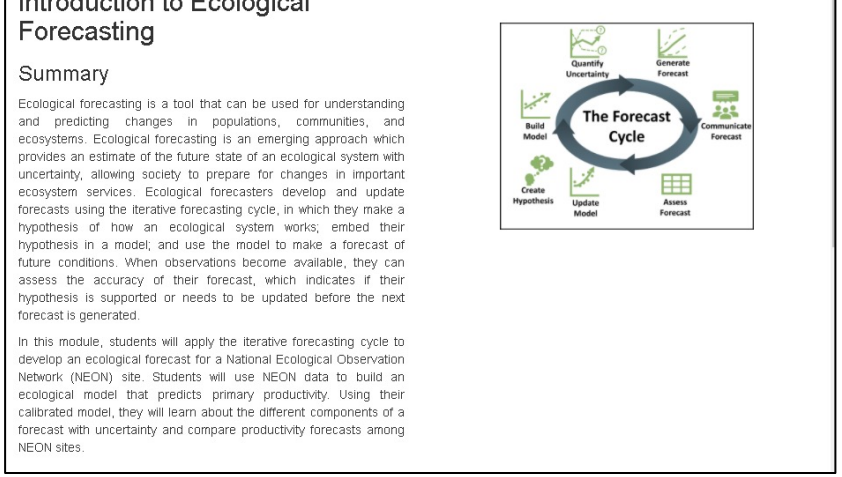
With a partner (work in pairs):

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



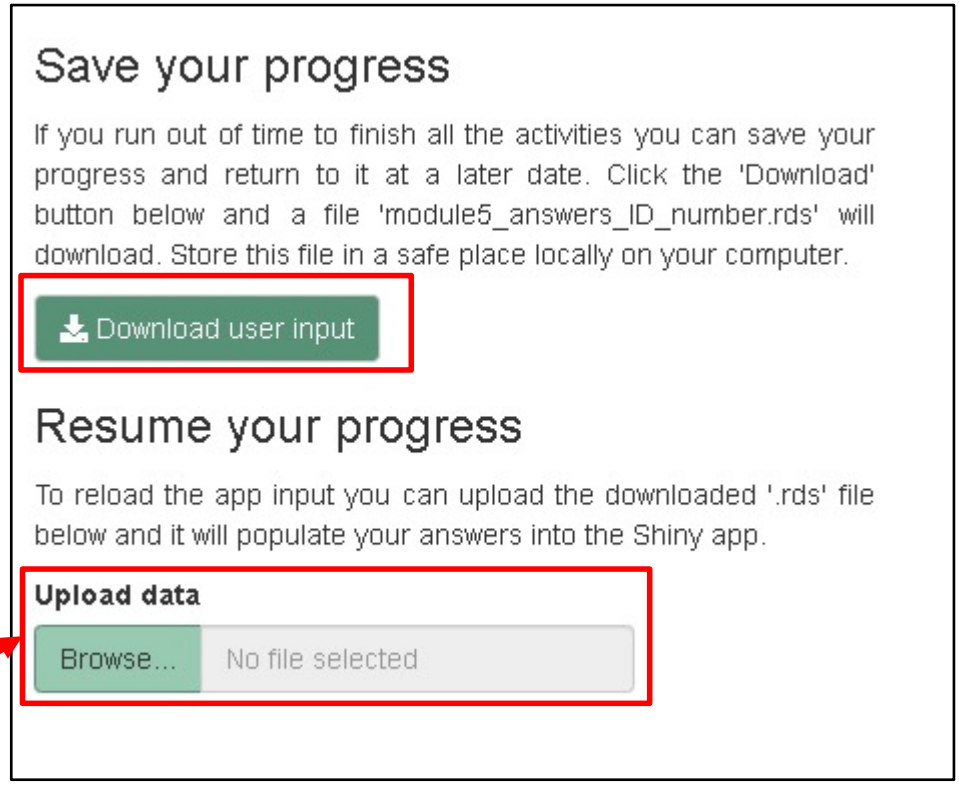
Let's Go!

- 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/

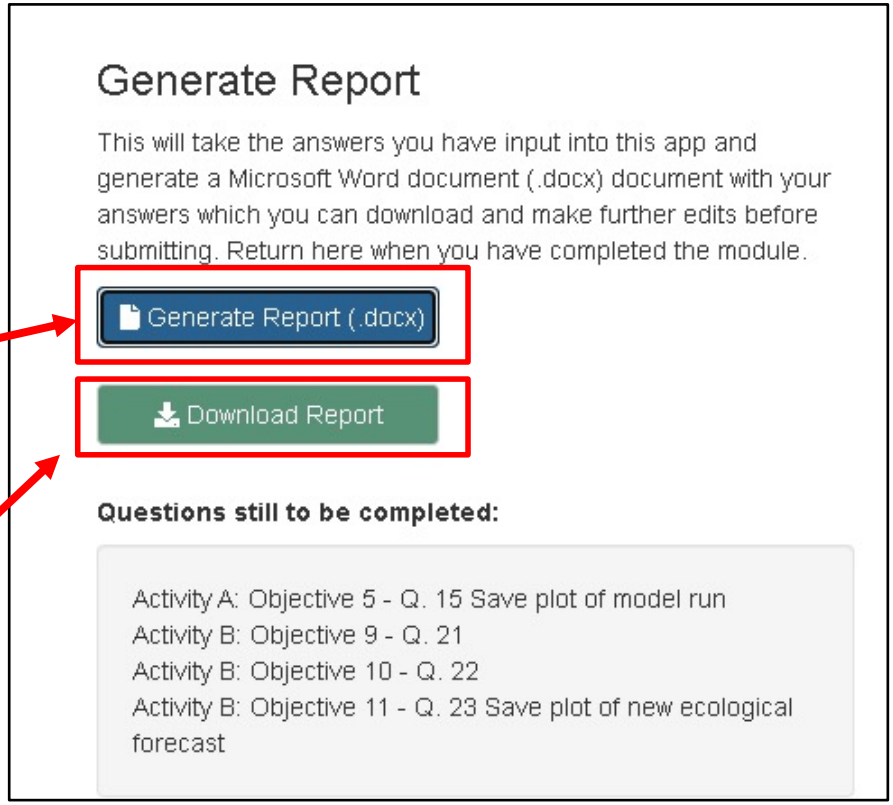
Saving & Resuming Progress

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



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.



Thank you for participating!

Stay tuned for future modules:

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

Find out more at:
macrosystemsEDDIE.org

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SERC the Science Education Resource Center at Carleton College

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:

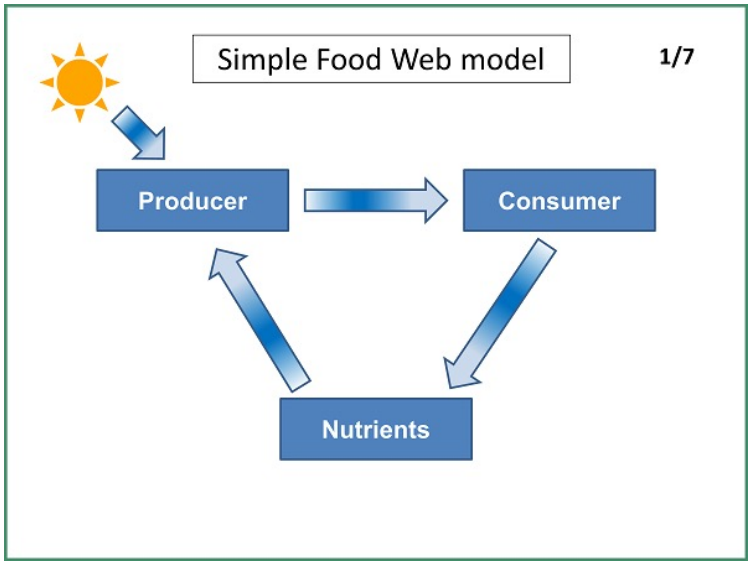
Quickstart:

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

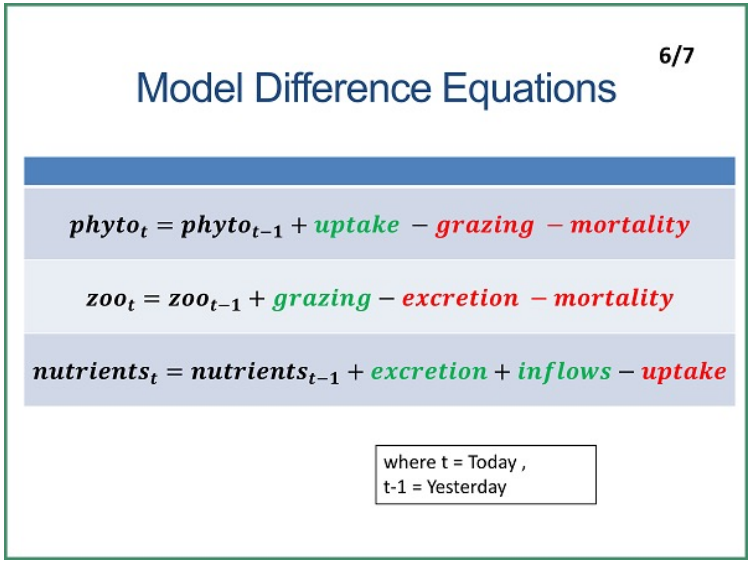
Models

Primary Production in Lakes

Conceptual Model

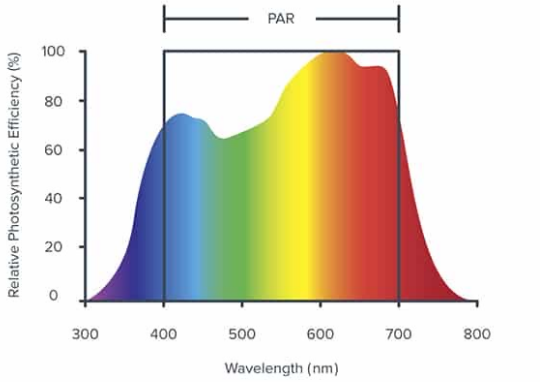


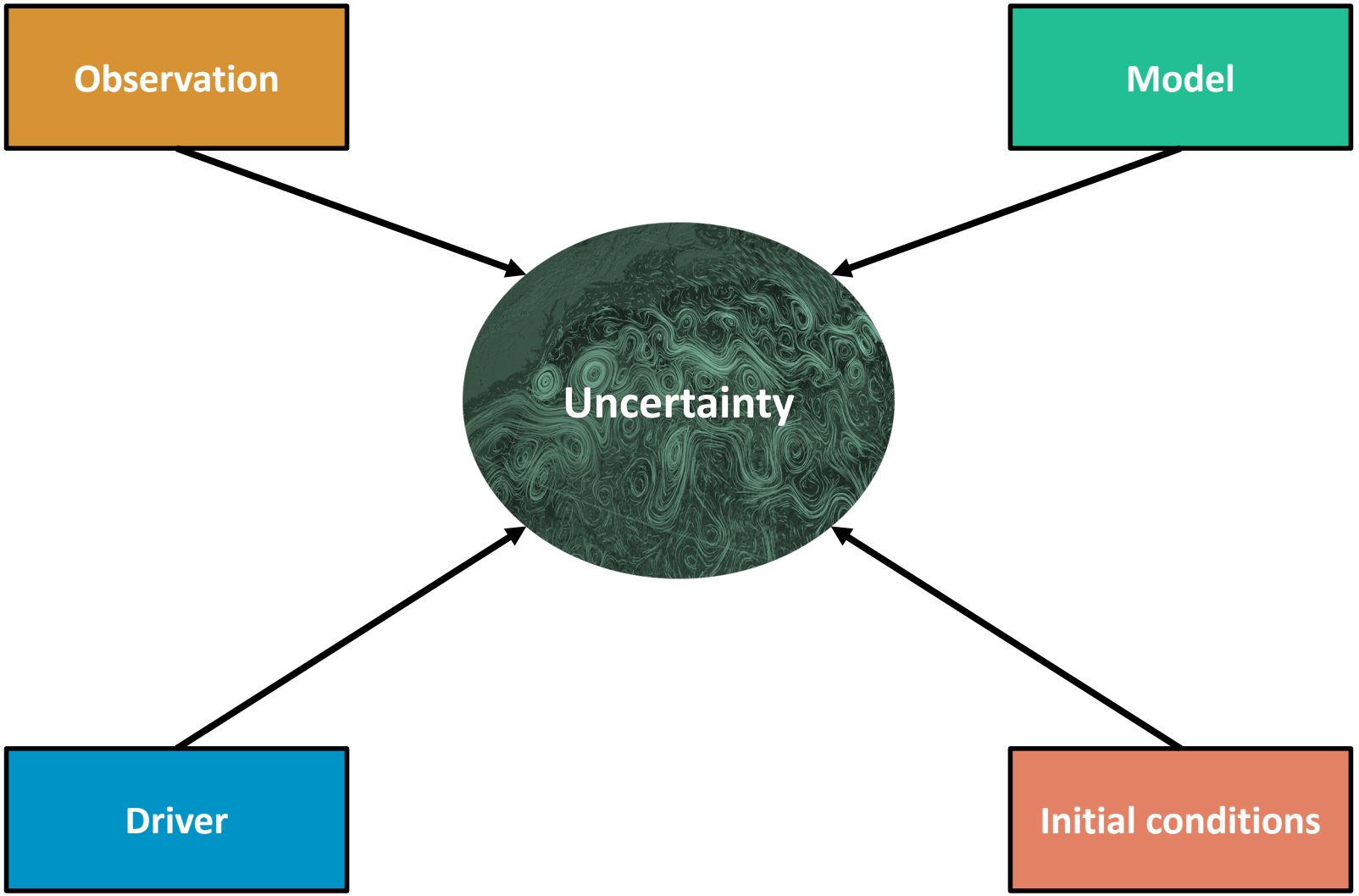
Mathematical Model



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 the spectral range of solar radiation from 400 to 700 nm that photosynthetic organisms use in the process of photosynthesis

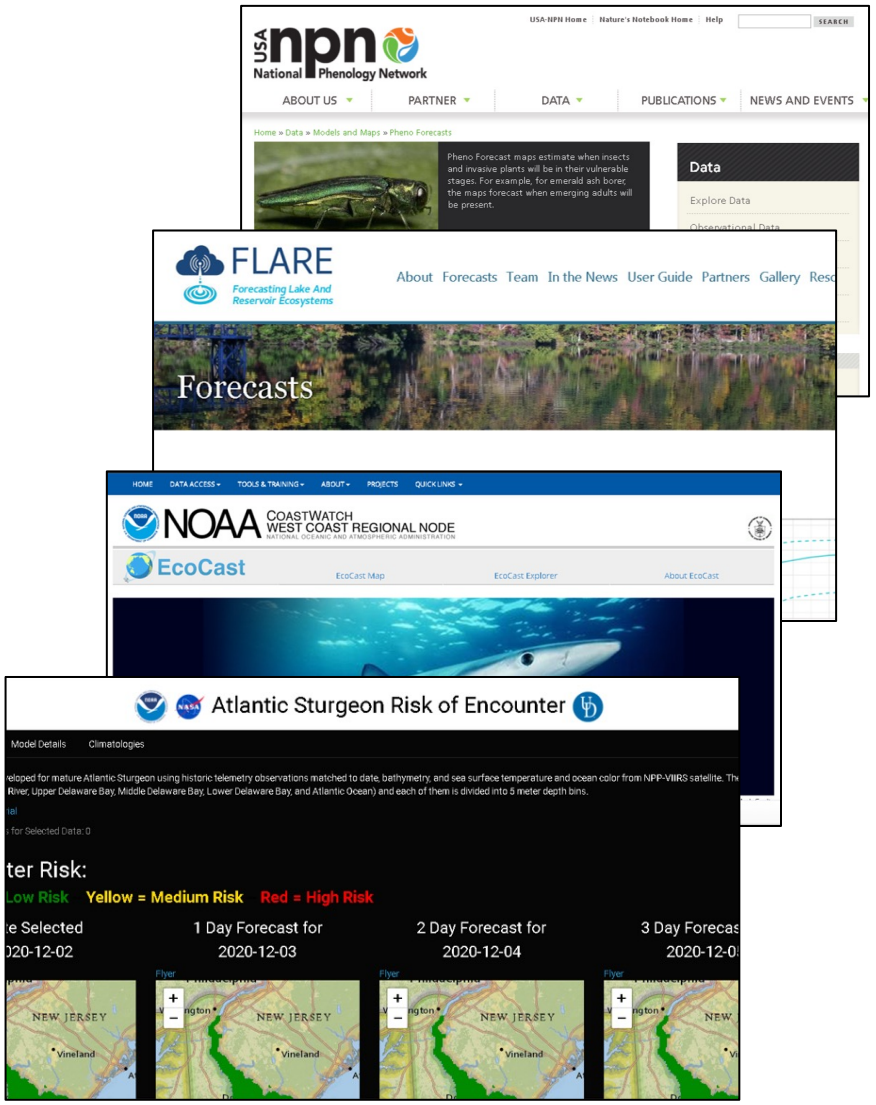



Observation
Model
Uncertainty
Driver
Initial conditions

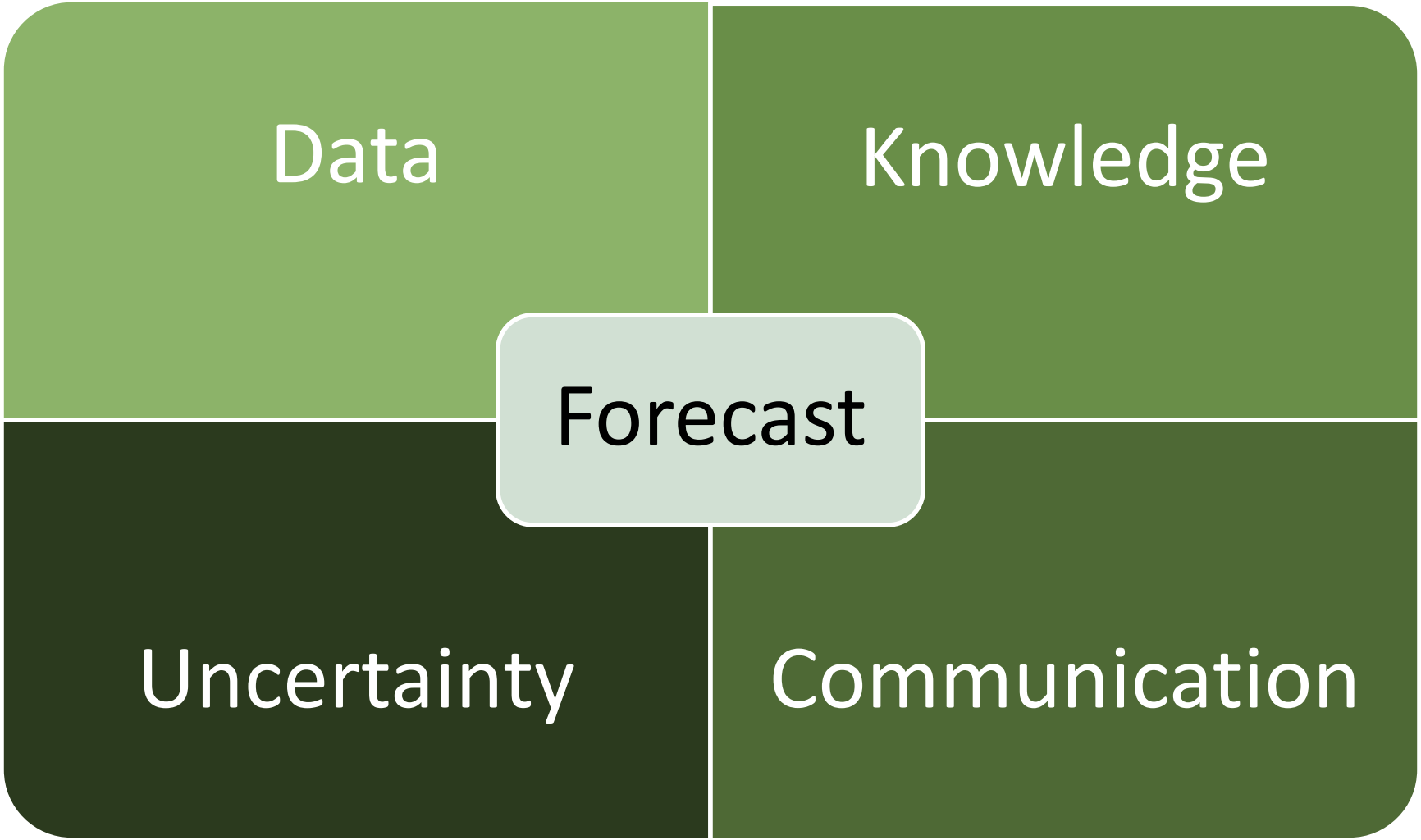
Ecological Forecast Examples

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…

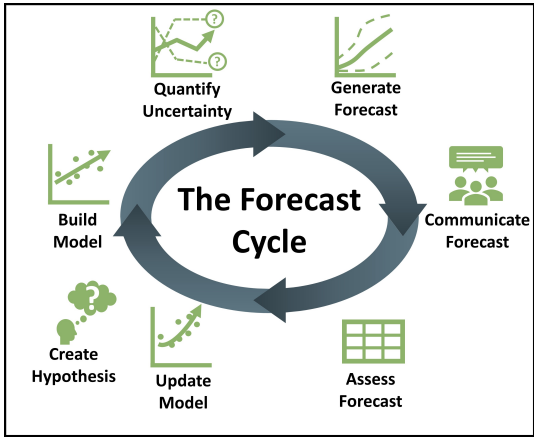


What do you think are the key components of a forecast?



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



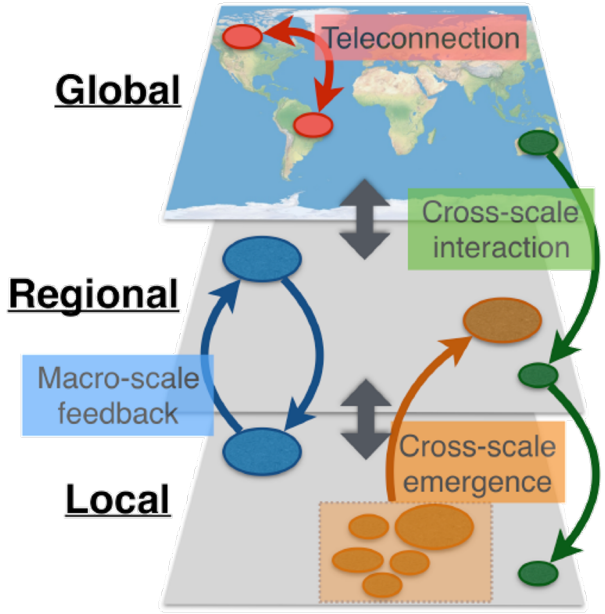


Figure modified from: Heffernan et al. 2014

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