

Macrosystems EDDIE: Using Ecological Forecasts to Guide Decision Making Instructor's Manual

Module Description

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.

The theme of this module is understanding how forecasts are connected to decision-making. Ecological forecasts have vast potential for aiding decision-making for range of different users, yet forecast results may be challenging to understand because they inherently are associated with uncertainty in alternate future outcomes which have not yet occurred. This module will teach students different ways to visualize forecasts; how uncertainty in forecast visualizations can influence decision-making; and to create their own visualizations of probabilistic ecological forecasts tailored to a specific user.

Pedagogical Connections

Phase	Functions	Examples from this module
Engagement	Introduce topic, gauge students' preconceptions, call up students' schemata	Short introductory lecture; pre-module questions to engage students in identifying forecasts they currently use in their lives
Exploration	Engage students in inquiry, scientific discourse, evidence-based reasoning	Investigation of forecast visualizations to identify how uncertainty is represented and how this varies among forecast variables and ecosystems
Explanation	Engage students in scientific discourse, evidence-based reasoning	Students role-play as decision-makers to decide how to manage a drinking water reservoir using multiple forecast visualizations with different representations of uncertainty
Expansion	Broaden students' schemata to account for more observations	Students explore a forecast output and customize a visualization for a new stakeholder

Evaluation	Evaluate students' understanding, using formative and summative assessments	Students answer questions and participate in discussion throughout the module to evaluate their understanding of the concepts
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Learning Objectives

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

- Describe what ecological forecasts are and how they are used (Activity A)
- Identify the components of a structured decision (Activity B)
- Discuss how forecast uncertainty relates to decision-making (Activity A, B, C)
- Match stakeholder needs with different levels of forecasting decision support (Activity B, C)
- Identify different ways to represent uncertainty in a visualization (Activity A, B, C)
- Create visualizations tailored to specific stakeholders (Activity C)

How to Use this Module

This entire module can be completed in one 2-3 hour lab period or two 60-minute lecture periods for introductory undergraduate students. Activities A and B could be completed with upper level students in one 60-minute lecture periods, with Activity C as a separate add-on activity.

We have found success with structuring the module so that the first time period consists of the instructor lecture (~20 minutes), followed by students independently working through the module, with class check-ins to discuss after each Activity is completed. Classes have found that students complete the Activities at different paces, so checking in with the students for group discussion between activities can be done when most students are ~80-90% finished the Activity. Students can complete the remaining activities independently outside of class time, with a brief check-in during the next class period.

This module is recommended for introductory undergraduate students in Ecology, Environmental Science/Studies, Data Science and Communication, and Environmental Social Science courses. Module Activities A and C can be tailored to focus on specific types of ecological forecasts for classes whose curriculum may be tailored to a specific ecosystem (e.g., terrestrial forecasts). Please contact us if you are interested in tailoring these activities to a different ecosystem.

We provide an introduction to ecological forecasts, stakeholder application, and uncertainty visualizations for instructors in the Instructor Manual and as part of the Teaching Materials, below. We recommend the instructor review these materials prior to teaching the module to help troubleshoot and respond to student questions.

Quick overview of the activities in this module

- 1) Introduction to the material: Pre-readings and PowerPoint in class
- 2) Activity A: Explore ecological forecast visualizations
- 3) Activity B: Make decisions using an ecological forecast
- 4) Activity C: Create a customized visualization for a specific stakeholder

Module Workflow (for either in-person or virtual instruction)

1. Give students their handout ahead of time to read over prior to class or distribute handouts when they arrive to class. The R Shiny app is set up for students to complete discussion questions as they navigate through the module activities. Thus, students could answer questions 1-3 prior to the start of instruction and can save their progress, which will allow them to return at a different time. The questions can be saved and downloaded as a Microsoft Word file at the end of the module, which could be submitted to their instructor for potential grading.
2. Give a brief (~20 minutes) PowerPoint presentation that introduces ecological forecasts and uncertainty, how forecasts can be used by stakeholders to guide decision-making, and describes different ways of visualizing forecast uncertainty. Slides notes are embedded within the PowerPoint document and included below.
3. After the presentation, the students transition to the Shiny App, where they can work individually or in pairs. For virtual instruction, we recommend putting two sets of partners (pairs) together (n=4 students total) into separate Zoom breakout rooms during this activity.
4. Student first complete Activity A. In this activity, students answer questions about ecological forecasts which they choose from a curated list of current forecasting systems and then compare their responses with a partner.
5. Once students complete Activity A, you can check in with students and have some group discussion regarding their visualization analysis and to answer any lingering questions. Group discussion questions for each activity are included below under the respective sections for each activity below. Then introduce Activity B and C with a few PowerPoint slides reminding students of the scope of the activities. For virtual instruction, this would entail having the students come back to the main Zoom room for a short check-in.
6. The students then return to their partner and pairs to complete Activity B, where they will role-play as drinking water managers and make decisions about optimizing multiple objectives using two different forecast visualizations (Activity B). Students first must use structured decision-making techniques to deconstruct their management objectives. They then create hypotheses about how to manage the drinking water reservoir as the forecasts are updated with observations and uncertainty changes over time, followed by discussion of how the different forecast visualizations influenced their ability to make decisions about managing the reservoir.
7. Once students complete Activity B, you can choose to check in with students and have group discussion using the guiding questions below.
8. The students then work individually on Activity C where they will choose a stakeholder of a drinking water quality forecast and customize a visualization for the stakeholder. Students identify a decision which their stakeholder needs to make (e.g., whether or not to go swimming in a lake based on a chlorophyll-a threshold) and answer questions which will guide their decisions in creating a customized forecast visualization. The students make a hypothesis about how different types of forecast visualizations will aid in their stakeholder's decision-making. Students then compare their visualizations with their partner (Activity C).

Important Note to Instructors:

The R Shiny app used in this module is continually being updated, so these module instructions will periodically change to account for changes in the code. If you have any questions or have other feedback about this module, please contact the module developers (see “We’d love your feedback” below).

We highly recommend that instructors familiarize themselves with the Shiny app prior to the lesson. This will enable you to be more prepared to answer questions related to certain areas of the app’s functionalities.

Things to do prior to starting the instructor’s presentation

- Practice going through the Instructor PowerPoint (see PowerPoint file and text below) and accessing the Shiny App.
- Have the students read through the pre-class student handout, especially the “Why macrosystems ecology and forecasting?” and “Today’s focal question” sections.
- **Optional:** Assign students the “Think about it!” questions in the Student Handout. These questions are design to be completed before class to get students thinking about how forecasts are used in their everyday life and develop a hypothesis regarding how forecast visualizations influence decision-making.

Introductory PowerPoint Presentation

Note: the numbers below match the PowerPoint slide numbers. The text for each slide is also in the “Notes” of the PowerPoint, so can be viewed when projecting in Presenter View. For teaching new materials, the slide notes can be read word for word. However, for introductory slides at the beginning of the powerpoint (e.g., TITLE SLIDE, PLAN FOR TODAY) and for the activities (LEARNING OBJECTIVES, ACTIVITY A, etc.), we leave the phrasing up to you and provide guidelines of what you might want to cover.

1. TITLE SLIDE

- Welcome the students to class. It might be helpful to go around the room and briefly discuss if anyone has experience with ecological forecasting, stakeholder analysis, or science communication. The point of this is to emphasize that most students are likely novices, and that asking lots of questions is ok because their peers are novices as well.
- It is really important at this point to emphasize that there will be lots of new material covered during this module, and that going slowly and asking for help is very much encouraged!

2. PLAN FOR TODAY

- Quick road map of what will be covered in the PowerPoint. We will briefly go over topics related to ecological forecasting, how ecological forecasts are used, and how we can use visualizations of forecasts to improve decision-making.
- Briefly go over the three activities

3. ECOSYSTEMS ARE CHANGING WORLDWIDE

- To start today, let's begin by thinking about why forecasts are made. As a result of numerous human impacts on ecosystems, historical conditions are no longer good indicators of how ecosystems will change in the future. Because of this ecological forecasts are critical for a number of reasons. They improve scientific understanding of ecological processes, aid in natural resource management, and enhance the ability of the public to make decisions regarding how they respond to and interact with natural resources

4. BEFORE WE START—WHAT IS A FORECAST?

- But what do we mean when we talk about 'forecasts' and what is a 'forecast' actually? For the purpose of today's lecture, a forecast is a prediction of a future event with uncertainty. This means that a forecast must be for an event which has not yet occurred, it must give a probability or likelihood of the event to occur (this is the uncertainty), and it should be actionable, meaning that it can inform some decision in order for someone to respond or adapt to the forecast.
- What are some examples of forecasts you have encountered in your lives (e.g. weather, disease, economic, elections)

5. ECOLOGICAL FORECASTS ARE A POWERFUL TOOL FOR PREDICTING ECOLOGICAL CHANGE

- When we think of ecological forecasts, it is important to think of them as being made within an iterative forecast cycle. This means that forecasts are made not just once, but many times, allowing improvements with each iteration.
- Because of this, they are a powerful tool for predicting ecological change. They allow you to start with a hypothesis about how you think an ecological variable will change, you build a model using this hypothesis, and quantify uncertainty around your prediction, and you produce a forecast. You then communicate your forecast to people who need it for decision-making, assess how well your forecast did, and then make updates and improvements before you start the cycle over.
- Importantly, forecasts are inherently tied to decision-making as decisions are always about the future!
- **As a result, we are focusing today on the communication component of the forecast cycle, which is critical to facilitating proper decision-making**

6. ECOLOGICAL FORECASTS ARE DIVERSE

- Ecological forecasts have a lot of diversity.
- Here we are seeing a forecast of water temperature for multiple days in the future at one location, where the black line shows the mean of the forecast and the uncertainty is represented by the pink area. Here is an example of another ecological forecast showing the risk of encountering an endangered species for one day in the future at multiple locations
- You can see there is a lot of variation in ecological forecasts, ranging from what variable is being predicted, how many locations it's being predicted in, and how it's being presented, among many other differences.

7. OPTIONAL: What other types of forecasts could you use?

- OPTIONAL class engagement slide, could be ecological forecasts specifically or other forecasts including weather, economic, political, sports, etc.
- Use this slide as a way to foster class discussion if time permits

8. WHO USES ECOLOGICAL FORECASTS

- There are many different types of people, or stakeholders, who can use forecasts to aid in their decision-making. More specifically, we can define a stakeholder as anyone who can use a forecast to gain understanding or to make a decision.
- This can range from natural resources managers to scientists to someone in the general public who is interested in learning more about a specific ecological variable. Forecasts are often made about ecological variables which have some value for decision-making. For example, the Spongy Moth (*L. dispar*) is an invasive moth which can wreak devastating havoc on the foliage of trees (seen in the picture on the bottom right). A forecast for distributions of spongy moths might have a number of different stakeholders, each of which might need to make different decisions. These could include (see bullets above). The last example, a family member, highlights an example where someone might not directly use the information to make a decision, but is interested in gaining more understanding of the ecological variable.

9. STAKEHOLDERS HAVE DIFFERENT NEEDS FOR INFORMING THEIR DECISIONS

- And each of these different stakeholders have different needs for informing the decisions they need to make. Based on these needs, we can loosely define 3 decision-use categories. The first is a casual user, who does not necessarily need detailed probabilistic forecasts in order to make their decisions. Secondly, we have practitioners, these are stakeholders who need to incorporate an overall idea of uncertainty in their decision-making. And lastly, we can think of decision analysts, who are stakeholders who require a detailed information on uncertainty in order to make decisions.
- If we go back to our *L. dispar* example, we can map on the same stakeholders to the decision-use categories. Park visitors or family members would fall under casual users because they don't need probabilistic forecasts in order to inform their decisions. Practitioners would include homeowners or landscaping business owners who need to have an overall idea of uncertainty in order to inform their decisions. And lastly a decision analyst might be a natural resource manager, who needs to make long-lasting decisions and should consider detailed information about uncertainty.

10. FORECASTS ARE INHERENTLY UNCERTAIN

- We calculate forecast uncertainty by running many different model simulations with slightly different conditions which we think represents the range of possible scenarios.
- For example, we don't know exactly how the weather is going to change in the future, so we run our forecast using many different possible weather outcomes, and then quantify the differences among the forecasts as part of the overall forecast uncertainty

11. OPTIONAL: WHAT ARE OTHER REASONS WHY THERE IS UNCERTAINTY IN FORECASTS

- OPTIONAL class engagement slide

- Other potential sources of uncertainty:
 - uncertainty in the processes which influence what you're predicting (model representation)
 - uncertainty in how other things driving your forecast might change (e.g., uncertainty in the tree population which spongy moths eat)
 - uncertainty in what you're actually measuring (e.g., uncertainty in being able to estimate spongy moth abundance)

12. FORECASTS ARE INHERENTLY UNCERTAIN (2)

- As a result of using multiple weather forecasts we get a **forecast with uncertainty**, which shows the range of different forecast outcomes.
- Here you are seeing the **mean** and **confidence interval** of all the different forecast runs, which is one common way to visualize uncertainty. But this type of visualization might not be best suited for all of the possible range of stakeholders, who are going to need different types of information to inform their diverse decisions

13. WHAT WAYS CAN WE COMMUNICATE UNCERTAINTY FOR STAKEHOLDERS?

- We can think of communicating forecast information in two broad categories. We can use the raw forecast output, or the numbers the model produces, and plot those values, along with some summary statistics, like the mean or median, and the 95% confidence interval.
- Another way to communicate forecast output is to create an index, which is based on some threshold which has importance for decision-making. For example, the raw forecast output on the left shows the modeled temperature output, whereas the figure on the right shows an index of high likely you are to encounter an endangered species. It is important to note that the figure on the right has been translated into this index of encountering a species, while the model likely outputs information on how abundant that species is in different locations.

14. WHAT WAYS CAN WE COMMUNICATE UNCERTAINTY? (1)

- Often times, uncertainty is represented in a forecast output using something like a reported range of possible values, or a confidence interval, like we saw with the water temperature forecast. However, in a forecast index, uncertainty is often translated into a probability based on the forecast output. This may be reported as a risk-level, or suitability of a certain forecast variable. We can see an example of this in the Risk of encountering Atlantic Sturgeon forecast.

15. WHAT WAYS CAN WE COMMUNICATE UNCERTAINTY? (2)

- Between these two categories of raw forecast output and forecast indices, we can think of different types of communications, which range from using numbers, words, icons, and figures to represent uncertainty.

16. WHAT WAYS CAN WE COMMUNICATE UNCERTAINTY? (3)

- We can communicate both forecast output and forecast indices using a number. For example, using our pollen forecast model, there is predicted to be 24 grains per cubic meter plus or

minus 4 grains per cubic meter, indicating some uncertainty in that prediction. Similarly, we can report the same information in an index that is relevant to allergen risk, and report that there is a 22% change of high allergen severity.

17. WHAT WAYS CAN WE COMMUNICATE UNCERTAINTY? (4)

- Because forecast output is already in the form of numbers, we can't apply a word visualization to summarize it. However, we can translate the forecast output into an index and communicate it using words. For example, a forecast of pollen concentrations could be communicated using an Allergen Severity Index, as shown here.

18. WHAT WAYS CAN WE COMMUNICATE UNCERTAINTY? (5)

- Our third category of uncertainty communication is the use of an icon. Similar to a word communication, we can't distill our forecast output into an icon, but we can use an icon to communicate an index. In this case, we use a familiar icon, a stoplight, to indicate the chance of allergen risk. In this forecast, the risk is low, so we see the green stoplight indicated. Icons are a good way to quickly represent information without the user having to spend much time analyzing the meaning.

19. WHAT WAYS CAN WE COMMUNICATE UNCERTAINTY? (6)

- Lastly, we can communicate uncertainty using a figure. There are many types of figures we can use to communicate uncertainty and we are just showing a few here. On the left, you can see how forecast output is plotted over time to show how the pollen concentration is predicted to change. On the right, the same data was used to convert into an index of pollen severity and the figure shows how the predictions are expected to change over space. Figures are a useful way to communicate a lot of information visually.

20. HOW DO WE VISUALIZE UNCERTAINTY FOR DIFFERENT DECISION USE CATEGORIES?

- And if we tie this back to our decision use categories, we can think about how we could represent uncertainty in different visualizations for each use case. While there is no perfect visualization for a single decision-use case, we can think of some general guidelines. For example, a park visitor, our casual user, might only need to know very minimal information, so we could use a word in a forecast index to say that the risk is 'low'. A homeowner might want to know a little more about the differing levels of uncertainty and might even want to know how the uncertainty varies in different areas surrounding their home to get a bigger picture of the situation. Lastly, a natural resource manager, or our decision analyst, is going to want very detailed information about both the quantities of spongy moth and the associated uncertainties, so a forecast output which includes uncertainty might be most informative for making a detailed decision. But a natural resource manager is likely going to want this information for a number of locations, possibly the entire range of the park they are managing. So coming up with ways to represent detailed information which includes uncertainty in a map is very important but also presents some challenges.

21. INCORPORATING UNCERTAINTY INTO MAPS

- But a natural resource manager is likely going to want this information for a number of locations, possibly the entire range of the park they are managing. So coming up with ways to

represent detailed information which includes uncertainty in a map is very important but also presents some challenges.

22. INCORPORATING UNCERTAINTY INTO MAPS (2)

- One way to provide detailed uncertainty while also including detailed forecast output is to use two separate figures, one showing the forecast output and one mapping the forecast uncertainty, here as a confidence interval. This figure here shows both the forecast median on the left, and the 95% confidence interval, representing uncertainty, on the right of a forecast of Malaria prevalence in Central Africa. Importantly, the figure on the left if shown alone, **does not represent any uncertainty**.

23. INCORPORATING UNCERTAINTY INTO MAPS (3)

- Another way to incorporate uncertainty is to translate a forecast output without uncertainty into a forecast index. Here, researchers have done this by taking a forecast of Sea Surface Temperature on the left, and converting that into a forecast index based on what scientists know about what water temperatures southern bluefish tuna like to live in. The goal of this forecast is to reduce the amount of bycatch of bluefish tuna for fisherman who are fishing for other species.
- The “OK zone” refers to the zone where few bluefish tuna are found and is “OK for fishing without restrictions” to avoid bycatch of bluefish tuna. The “core zone” represents areas of prime suitability for bluefish tuna and should not be fished without restrictions. Buffer zone refers to an intermediate region (buffer habitat).

24. HOW DO FORECAST VISUALIZATIONS INFLUENCE DECISION-MAKING?

- And so does it matter how we communicate forecast output?
We know that visualizations can be critical in helping stakeholders understand forecast output. However, the way uncertainty is represented has a proven influence on how people make decisions (e.g., Ramos et al. 2014, Cheong et al. 2016). Which means that considering decision needs of a stakeholder can help improve the usefulness of the visualization

25. OUR FOCAL QUESTION: HOW CAN ECOLOGICAL FORECASTS AND THEIR VISUALIZATIONS AID IN DECISION-MAKING?

- Today’s focal question is ‘How can ecological forecasts and their visualizations aid in decision-making?’

26. LEARNING OBJECTIVES

- Learning objectives!
- Talk through these with the students one by one: use the embedded animations to sequentially show each of the bullet points.
- Most importantly, the goal here is to have students develop their own hypotheses for how decision-making can be influenced by forecast uncertainty

27. SHINY APP

- The module can be accessed at: <https://macrosystemseddieshinyapps.io/module8/>

- This is an interactive webpage built using R code
- It has interactive plots and options embedded which allow you to complete the activities and answer questions

28. ACTIVITY A: EXPLORE AN ECOLOGICAL FORECAST

- Introduce Activity A, which has 2 objectives:
 - Familiarize yourself with an ecological forecast by identifying the basic components of a forecast, forecast stakeholders, stakeholder usage, and how forecasts are visualized
 - Compare forecasting systems to see how ecological forecasts can vary among ecosystems or ecological variables
- The main take home here is that students will be analyzing forecast visualization and comparing between different visualizations.
- Have students work in pairs as described earlier.

29. ACTIVITY B: MAKE DECISIONS USING AN ECOLOGICAL FORECAST

- Introduce Activity B, which has three objectives.
- The important take-home message here is that students need to
 - 1) first examine the decision they will make as a drinking water manager,
 - 2) make decisions using two different types of visualizations, one which includes uncertainty and one which does not, and
 - 3) answer questions and explore ideas around how the visualizations influenced their decision-making and how uncertainty changed over time.

30. ACTIVITY C: CREATE A CUSTOMIZED VISUALIZATIONS FOR A SPECIFIC STAKEHOLDER

- Introduce Activity C., which has 3 objectives
- The main take home for this activity is that students will
 - 1) pick a stakeholder of their choosing and identify a decision their stakeholder needs to make,
 - 2) explore the ensemble forecast which makes up their data,
 - 3) create a visualization within the app that is tailored to their stakeholder's needs, and
 - 4) explain why they chose that visualization and how a different stakeholder may or may not need the same visualization.

31. SAVING AND RESUMING PROGRESS

- This slide gives details on how students can save and resume progress should they need to complete the activities over multiple sittings

32. DOWNLOADING THE REPORT

- Generating the student report.
 - Stop the presentation here and navigate to the Shiny App while screen sharing.
 - Briefly demonstrate how to navigate between Activity Tabs and objective tabs within each Activity.

- Demonstrate the buttons regarding saving your progress and resuming your progress and the “Generate Report” feature.
- Make sure to emphasize to students to read through the text carefully as there are instructions there if they get confused. Also encourage them to feel free to ask questions if they don’t understand what to do.
- At this point send the students into breakout rooms of ~4 (2 pairs each) and let them get started on the Shiny App.
- Identify if the saved report will be submitted as an assignment and which app questions need to be completed as part of the activity.

33. LET’S GO!

- Give the class an overview of the structure for completing the modules (e.g., if they will have scheduled breaks, scheduled times to return to the full group, how many of the activities they are expected to complete during today’s class period vs. individually vs. a subsequent class period)
- Instruct students to navigate to the shiny app and begin!

Shiny App Content

Common stumbling blocks with the Shiny app:

- If the app disconnects due to inactivity, students will lose their progress. They should save/download the .eddie file with their answers often!
- If students have issues with app functionality, have them check that they have turned off privacy blockers in their web browser.

Module Overview

This is the landing page of the Shiny app. It gives an overview of the module. There are no questions students need to complete on this tab.

Presentation

This tab is home to selected slides from the Introductory PowerPoint to serve as a resource for students as they are completing the module. There are no questions students need to complete on this tab.

Introduction

This outlines the workflow and navigation of the module. This tab is an informational tab which outlines the module workflow, directions on how to save and resume progress, how to generate and download their answers once completed, and a list of answers which remain unanswered. In this tab, students will also input their name and student ID number into the text boxes in order to associate this with their answers once the module is completed.

Activity A: Explore an existing ecological forecast

Activity A challenges the students to look at existing ecological forecasts and answer questions which will help them understand how different visualizations represent uncertainty. Before you let them work independently in their pairs, open the RShiny App on your computer and project it to show them the interface. Show them how to enter their Class ID, access the list of ecological forecasts, and answer the questions within the app. You might also want to provide an example of how to save and resume progress, as well as download the final report. Walk around the pairs and make sure that everyone is able to access the ecological forecasts.

Group Discussion Questions for Activity A include:

- Ask students to present the visualization they and their partner chose. Discuss the differences (or similarities!) in whether the visualization used forecast output or an index, whether uncertainty was represented, whether the figure included a map, numbers, icons, what types of stakeholders could use the forecasts, what are their decision-use categories, etc.
- Are there some visualizations that make it more difficult to represent or understand uncertainty? What does this mean for designing visualizations for stakeholders which do or do not represent uncertainty?
- How did they find determining whether the visualization used a forecast output or a forecast index?
- How did they find determining whether or not the visualization included uncertainty?

Common stumbling blocks for Activity A include:

- Objective 1: sometimes students will click the link and go directly to the website vs using the image itself to answer the questions. The questions in the app are designed to be answered only with the image embedded in the shiny app. This is because some of the websites host multiple forecasts and forecast visualizations, and we curated this selection of forecast visualizations for this activity. Students are welcome to use the websites to learn more about the forecasts, but should answer the questions only from the visualization within the shiny app.
- Objective 1 and 2: if the images are too small, students can right click to open a larger version of the image in a new browser window.
- Objective 1: once students click on an image, it should appear down below so that they can reference it for the questions.
- Objectives 1 and 2: students should work in pairs to discuss their answers.

Activity B: Make decisions informed by a water quality forecast

Activity B pushes the students to role-play as decision makers in a guided scenario which includes balances numerous decision objectives.

Group Discussion Questions for Activity B include:

- Ask students to present their decision figure from Objective 5. What was the most important thing influencing their decision? How does this differ among students and relate to the decisions they made?
- What other ways could uncertainty have been represented in this forecast visualization?
- For what reasons might you want to use forecast output visualization instead of the forecast index visualization? And vice versa?

Common stumbling blocks for Activity B include:

- Objective 3: Issues with seeing all of the ProACT components on one screen. Depending on your computer screen size, sometimes the last column (Trade-Offs) shows up on a second row. Inform students that they should look below the other columns if they don't see 'Trade-Offs' show up
- Objective 3: Issues in the ProACT question with dragging the answers into the different columns. Some students have trouble selecting and dragging the answers and end up highlighting them instead. Inform them that this may be an issue and to have patience with the question!
- Objective 3: Checking answers in the ProACT question. There are many different answers to sort through and some of the columns have more than one answer. Encourage students to think critically and use the example powerpoint above to help them apply this decision theory tool to their scenario. They can move answers around and keep checking them below until they answer them all correctly.

ProACT Answers:

Problem	Objective	Alternative Decisions	Consequences	Trade-Offs
You must optimize multiple objectives when managing the reservoir at a time when algal blooms are likely	Provide safe drinking water	Treat the reservoir with an algaecide	Economic benefit is heavily decreased due to canceling the event	Swimmer safety is compromised, but economic benefit and ecological health remain high due to avoiding algaecide treatment
	Maximize economic benefit	Cancel the event	Decreased ecological health (e.g. death of aquatic	Decrease in ecological health but safe drinking water is ensured

			organisms) due to algaecide treatment	
	Ensure swimmer safety	Continue with the event	Compromised drinking water quality due to lack of treatment during an algal bloom	Small loss of money due to cost of algaecide, but increased economic benefit to the city from the event
	Protect ecological health			

- Objectives 4a and 4b: Once you choose to ‘Cancel the event’, all of the remaining decisions in that Objective will automatically default to ‘Cancel the event.’ This decision cannot be undone!
- Objective 5: When answering questions about how the forecasts change over time, students can add/remove components of the time series plot to help them. By clicking on items in the legend, items can be removed/added onto the plot to allow it to be easier to read.

Activity C: Compare different ways of visualizing ecological forecasts

As a culminating check-in, ask students to prepare a short presentation of their visualizations and justify why they have chosen them for their stakeholders. Spend some time going around the classroom so that each student or student pair can present their final visualizations (these can be emailed to the instructor and presented together or presented by individual students via screen sharing if teaching in a virtual format). Ask probing questions and initiate a class discussion in which the other students respond to questions, and ask their own.

Group Discussion Questions for Activity C include:

- Ask students to present their custom visualizations to the class.
- What other types of visualizations not included as options here might you want to consider?
- Are there visualizations included here that may not be very good representations of the forecast?
 - E.g., sometimes visualizations that people “like” are not always the visualizations that lead to the most effective “understanding”
- How would co-development with an actual stakeholder influence and improve their visualizations?
- How would iterative design of visualizations aid in usability for decision-making?
- How would you balance the needs of multiple stakeholders if you were to only create one visualization rather than customized visualizations for specific needs?
- How do you think interactive visualizations would influence decision-making?

27. THANK YOU FOR PARTICIPATING!

Resources and References

Optional pre-class readings and video:

Tools and high-frequency data that we will use in this module:

Recent publications about EDDIE modules:

- Carey, C. C., R. D. Gougis, J. L. Klug, C. M. O'Reilly, and D. C. Richardson. 2015. A model for using environmental data-driven inquiry and exploration to teach limnology to undergraduates. *Limnology and Oceanography Bulletin* 24:32–35.
- Carey, C. C., and R. D. Gougis. 2017. Simulation modeling of lakes in undergraduate and graduate classrooms increases comprehension of climate change concepts and experience with computational tools. *Journal of Science Education and Technology* 26:1-11.
- Klug, J. L., C. C. Carey, D. C. Richardson, and R. Darner Gougis. 2017. Analysis of high-frequency and long-term data in undergraduate ecology classes improves quantitative literacy. *Ecosphere* 8:e01733.
- Farrell, K.J., and C.C. Carey. 2018. Power, pitfalls, and potential for integrating computational literacy into undergraduate ecology courses. *Ecology and Evolution* 8:7744-7751. DOI: 10.1002/ece3.4363
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We'd love your feedback!

We frequently update this module to reflect improvements to the code, new teaching materials and relevant readings, and student activities. Your feedback is incredibly valuable to us and will guide future module development within the Macrosystems EDDIE project. Please let us know any suggestions for improvement or other comments about the module at

<http://module8.macrosystemseddie.org> or by sending an email to MacrosystemsEDDIE@gmail.com

Answer Key

Q1. What is the name of the forecasting system you chose?

- Answer can be 1 of 9. Use the number associated with each student's answer to check the answers for Question 2-7
 1. USA-NPN Pheno Forecast
 2. Smart & Connected Communities
 3. EcoCast
 4. Atlantic Sturgeon Risk of Encounter
 5. Naturecast Phenology Forecasts
 6. Portal Forecast
 7. Coral Reef Watch
 8. GrassCast
 9. Phenology at the Morton Arboretum

Q2. What ecological variable(s) are being forecasted?

1. USA-NPN Pheno Forecast: Emerald Ash Borer activity
2. Smart & Connected Communities: Lake water temperature
3. EcoCast: suitability for fishing off the coast of California
4. Atlantic Sturgeon Risk of Encounter: risk of encountering Atlantic Sturgeon species
5. NatureCast Phenology Forecast: predicted date of leaf out for Gingko biloba trees across the United States
6. Portal Forecast: rodent abundance
7. Coral Reef Watch: Coral Reef Bleaching Stress Index
8. GrassCast: grassland productivity
9. Phenology at the Morton Arboretum: probability of bud burst of Quercus macrocarpa

Q3. Does the visualization represent uncertainty?

1. USA-NPN Pheno Forecast: No
2. Smart & Connected Communities: Yes
3. EcoCast: Yes
4. Atlantic Sturgeon Risk of Encounter: Yes (this is a tricky one for students—because the forecast represents a forecast index which incorporates a risk based on some threshold calculated by the forecasters, it does include a component of uncertainty)
5. NatureCast Phenology Forecast: No
6. Portal Forecast: rodent abundance: Yes
7. Coral Reef Watch: Yes, this figure represents the 60% likelihood outcome
8. GrassCast: No
9. Phenology at the Morton Arboretum: Yes

Q4. Is the visualization presenting forecast output or a forecast index?

1. USA-NPN Pheno Forecast: forecast index
2. Smart & Connected Communities: forecast output
3. EcoCast: forecast index
4. Atlantic Sturgeon Risk of Encounter: forecast index
5. NatureCast Phenology Forecast: forecast index
6. Portal Forecast: forecast output
7. Coral Reef Watch: forecast index
8. GrassCast: forecast index
9. Phenology at the Morton Arboretum: forecast index

Q5. Describe how the forecast is visualized (e.g., does it use words, numbers, icons, figures, etc. to represent its predictions?). If you answered 'yes' to Q3, make sure to also include a description of how uncertainty is visualized. If you answered 'no' to Q3, include a description of how uncertainty could be visualized.

1. USA-NPN Pheno Forecast: This visualization uses a map as a figure to communicate the forecast index which is based on GDD (growing degree days) and how that affects Emerald Ash Borer activity. Uncertainty is not represented. Uncertainty could be represented by including a separate figure which shows the range of uncertainty around these predictions on the map.
2. Smart & Connected Communities: This visualization uses a time series figure to communicate the forecast output at multiple depths. Uncertainty is communicated using a 95% confidence interval as separate lines around the mean forecast.
3. EcoCast: This visualization uses a map as a figure to communicate the forecast index of what locations are better to fish in. This is based on the likelihood of bycatch of different protected or threatened species (where there is a higher likelihood of bycatch is a 'poorer to fish' location).
4. Atlantic Sturgeon Risk of Encounter: This visualization uses a map as a figure to communicate the risk of encountering an endangered species, the Atlantic Sturgeon.
5. NatureCast Phenology Forecast: This visualization uses a map as a figure to communicate the date that leaf out will occur across the country for a particular tree species. Uncertainty is not represented. Uncertainty could be represented by including a separate figure which shows the range of uncertainty around these predictions on the map.
6. Portal Forecast: This visualization uses a time series figure to show forecasted rodent abundance over time. Uncertainty is represented as a 95% confidence interval.
7. Coral Reef Watch: This visualization uses a map as a figure to show the heat stress index for coral reef bleaching. The index is represented via multiple categories. This represents uncertainty by stating that it is 60% probability outcome.

8. GrassCast: This visualization uses a map as a figure to show the predicted change in grassland productivity from the historical average. It does not represent uncertainty. Uncertainty could be represented by including a separate figure which shows the range of uncertainty around these predictions on the map.
9. Phenology at the Morton Arboretum: This visualization uses a time series figure to show the likelihood of bud burst for given days of the year. Uncertainty is incorporated in the forecast index which is represented on the figure, the probability of bud burst occurring.

Q6. Name on stakeholder who could use this forecast. This can be hypothesized by you or come directly from the website.

- Answers for each include, but are not limited to the following:
 1. USA-NPN Pheno Forecast
 2. Smart & Connected Communities
 3. EcoCast
 4. Atlantic Sturgeon Risk of Encounter
 5. Naturecast Phenology Forecasts
 6. Portal Forecast
 7. Coral Reef Watch
 8. GrassCast
 9. Phenology at the Morton Arboretum

Q7. Classify the stakeholder identified in Q6 into a decision-use category that best fits their decision needs.

- Answers depend on student's answer to Q6 but examples include
 - Water resource manager: decision analyst
 - Homeowner: practitioner
 - Tourist: casual user

Q8. What ecological variable was forecasted in your partner's system?

- Answers depend on which systems have been chosen by the students

Q9. What are the major differences and similarities between the two systems' visualizations?

- Answers depend on which systems have been chosen by the students. However, students should discuss things like ecological variable being predicted, what ecosystems are represented, what types of stakeholders might use the forecast, whether the forecast predicts in time, space, or both, whether uncertainty is included in the forecast visualization, how uncertainty is represented, etc.

Q10. Which visualizations represent forecast uncertainty?

- Answers depend on which systems have been chosen by the students. See Q3 for a list of which forecasts include uncertainty.

Q11. Does your partner's visualization use a forecast index or forecast output?

- See Q4 for a list of which forecasts use forecast index or forecast output.

Q12. Name one stakeholder who could use your partner's forecast. This can come directly from the website or can be hypothesized by you.

- This question can have many possible answers depending on which forecast system the students have chosen.

Q13. Of the two forecast systems being compared, which do you think is most useful for guiding stakeholders? Why?

- There are many possible answers to the this questions. However, students should consider the variable being forecasted, what types of stakeholders might use it and for what decision application, the decision needs of stakeholders, how the forecast is visualized, whether a forecast index or output is used, etc.

Q14. Drag the definitions from the box on the left to the corresponding boxes on the right.

Problem	Objective	Alternative Decisions	Consequences	Trade-Offs
You must optimize multiple objectives when managing the reservoir at a time when algal blooms are likely	Provide safe drinking water	Treat the reservoir with an algaecide	Economic benefit is heavily decreased due to canceling the event	Swimmer safety is compromised, but economic benefit and ecological health remain high due to avoiding algaecide treatment
	Maximize economic benefit	Cancel the event	Decreased ecological health (e.g. death of aquatic organisms) due to algaecide treatment	Decrease in ecological health but safe drinking water is ensured
	Ensure swimmer safety	Continue with the event	Compromised drinking water quality due to lack of treatment during an algal bloom	Small loss of money due to cost of algaecide, but increased economic benefit to the city from

				the event
	Protect ecological health			

Q15. What was the final algal concentration observed on June 6, if treatment had not occurred?

- In order to make the forecasts dynamic and diverse each time the module is taught, the values are independent for each class sitting. Because of this, you will need to check the figure of the forecast in order to determine the final concentration.

Q16. Was the range of uncertainty around the forecast for June 6 greater in the 14-day or 2-day forecast?

- The range of uncertainty is larger in the 14-day forecast.

Q17. In this Activity, you made a decision about an event 2 weeks into the future. Based on your answer to Q16, do you think there would be more or less uncertainty around a forecast that was made for 2 months into the future?

- As ecological forecasting is still a developing field which aims to predict numerous ecological variables with diverse dynamics, the answer to this question is not well agreed upon. However, it is generally accepted that in most situations, uncertainty increases the further you predict into the future.

Q18. Describe how your decisions were different between Objective 4a and 4b.

- This question does not have a correct answer but students should discuss how the forecast output (4a) or forecast index (4b) influenced their decision-making as a water resource manager.

Q19. What makes the visualization in Objective 4a different from Objective 4b?

- Objective 4a uses a forecast output and Objective 4b uses a forecast index.

Q20. Which of the four objectives were you most concerned with optimizing?

- This question is dependent on student preferences when completing the decision exercise.

Q21. Which visualization did you prefer as a drinking water manager?

- This question is dependent on student preferences when completing the decision exercise.

Q22. Name one decision that your stakeholder could make if they were given a water quality forecast.

- This question is dependent on student preferences when selecting a stakeholder.

Q23. Classify your stakeholder into a decision-use category that best fits their decision needs.

- This question is dependent on student preferences when selecting a stakeholder.

Q24. What is the mean concentration of all the forecasts?

- Similar to Q15, because the distribution of the forecast is subject to change over time, this answer may change from class to class. You can easily check this answer by completing the activity within the app for your class.

Q25. What is the minimum concentration of all the forecasts?

- Similar to Q24, because the distribution of the forecast is subject to change over time, this answer may change from class to class. You can easily check this answer by completing the activity within the app for your class.

Q26. What is the minimum concentration of all the forecasts?

- Similar to Q25, because the distribution of the forecast is subject to change over time, this answer may change from class to class. You can easily check this answer by completing the activity within the app for your class.

Q27. What is one reason why there is uncertainty among these forecast estimates?

- As given as an example in the introductory powerpoint, differences in weather forecasts which drive the forecast of water quality can lead to uncertainty. Other examples include uncertainty in the values of parameters in the model, uncertainty in the initial observations or conditions when the forecast is made, or uncertainty in the ability of the model to predict the ecological dynamics.

Q28. Why did you choose a forecast index or output?

- This is a discussion question intended to get students to think about their choices and does not have a specific answer.

Q29. Why did you choose the communication type that you did (e.g., word, number, icon, or figure)?

- This is a discussion question intended to get students to think about their choices and does not have a specific answer.

Q30. If you chose a figure representation, why did you choose the plot type that you did (e.g., pie, time series, bar graph)?

- This is a discussion question intended to get students to think about their choices and does not have a specific answer.

Q31. What other groups of people could use a forecast of algal concentrations?

- Possible answers include but are not limited to: lake recreationists, environmental policy representatives, homeowners on nearby lakes, water quality consultants, etc.

Q32. Pick one of the stakeholders you identified in the above question. What is their decision-use category?

- This answer depends on the stakeholder chosen in Q31.

Q33. If you were customizing a visualization for this stakeholder, how might you alter your current visualization?

- This answer depends on the stakeholder chosen in Q31 and is intended to guide students in thinking about how different users might need different types of visualizations and included information.