# 2023 AARMS-EIDM Summer School

Placeholder

## Instructors

## Guest lecturers

## Funding

# Course 1. Mathematical Epidemiology

Placeholder

# Course 2. Data, models, and decision support

Placeholder

# Schedule - Week 1

Placeholder

# Schedule - Week 2

Placeholder

# Problems - Mathematical Epidemiology

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# Problems - Data, Models, and Decision support

* **Problems 2.1. Why make models & From models to forecasts** (see syllabus and Ch 2 of Dietze - Watmough; TA - Forero)
  + [Problems 2.1](probs-2-1.html)
* **Problems 2.2 Parameter estimation from the literature and Introduction to Bayes** (Ch 5 of Dietze - Watmough; TA - Falcao)
  + [Intro to JAGS](https://github.com/EcoForecast/EF_Activities/blob/master/Exercise_05_JAGS.Rmd)
* **Problems 2.3 Characterizing uncertainty** (Ch 6 of Dietze - Hurford; TA - Anokye)
  + [Problems 2.3](#probs-2-3)
* **Problems 2.4 Latent variables and fusing data sources** (Ch 8 & 9 of Dietze - Hurford; TA - Falcao)
  + [Problems 2.4](#probs-2-4)
* **Problems 2.5 Propagating uncertainty** (Ch 11 of Dietze - Hurford; TA - Anokye)
  + [Problems 2.5](#probs-2-5)
* **Problems 2.6 Data assimilation** (Ch 13 and 14 of Dietze - Arino; TA - Anokye)
* **Problems 2.7 Assessing model performance and case studies** (Ch 7, 10, 12, 15 and 16 of Dietze - Watmough; TA - Falcao)
  + [Problems 2.7](#probs-2-7)
* **Problems 2.8 Models for decision support** (Ch 17 of Dietze)
  + [Problems 2.8](#probs-2-8)

# Projects

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## Project details

## Possible projects

# Final projects

Final projects that were completed as part of the AARMS-EIDM summer school were:

1. **Conditions for forming and suspending the Atlantic bubble** by Tanuja Das, Ravindu Upasena, Qiuyi Su, Tangjuan Li, and Yurong Zhang. Defines promising mathematical conditions forming and suspending a travel bubble.
2. **An SEIR model with pandemic fatigue** by Rhiannon Loster, Benjamin Benteke, and Pengfei Yue
3. **Topical Acaricides on Rodents as a One Health Intervention Against Lyme Disease: A Epidemiological Modelling Study** by Bruce Chidley, Lauren Farrell, Geneva Liwag, Thaneswary Rajanderan, and Sophie Stelmach
4. **Investigating the conditions for locally transmitted dengue infections** by Leyi Jiang, Grace Nichol, and Michele Bergevin
5. **Exploring Cross-Species Transmission through ODE Models Informed by Phylogenetic Analysis** by Sana Naderi and Norma Forero.
6. **Modelling Human Induced Allee Effects on Biological Invasion in a Two Patch Model** by Manuel Perez, Elise Woodward, and Zahresh Walji
7. **An SIARV model: dynamics and data fitting** by Jessa Marley, Shab Molan, Francisca Olajide, and Greg Forkutza
8. **A Time-Delayed and Drug-Controlled Within-Host Model** by Rushi Chaudhary, Shiheng Fan, Tian Hou, Zhimin Li, and Yuanxi Yue
9. **Investigating the spread and establishment of Chikungunya in Florida through stochastic and deterministic modelling** by Antonio Gondim, Leonardo Shultz, and Rebeca Falcao
10. **Weather and *Chikungunya* transmission dynamics** by Rebeca C Falcao, Antonio Mateus Gondim, and Leonardo Schultz
11. **A two patch model of dengue fever dynamics** by George Adu-Boahen, Francis Anokye, Joseph Baafi, and Giuseppe Pasquilino

# Participant demography

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## Affiliation

## Career stage

## Degree program/primary area

## Gender, Indigenous Peoples, visible minitories, persons with disabilities

# Conditions for forming and suspending the Atlantic bubble

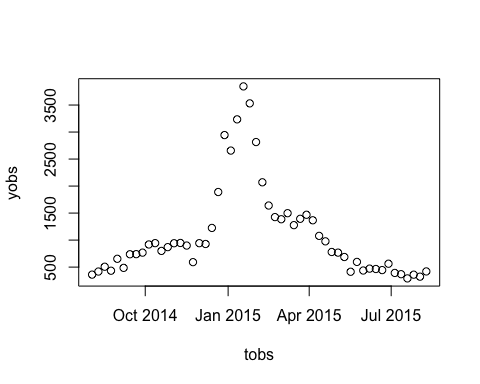
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## Background

# Problems 2.7 Assessing Model Performance

1. Rework [problem 2.4](probs-2-4) exercise 2, but restrict the data to a single year. For example, just use data after August 1st, 2014.

gflu = read.csv("https://raw.githubusercontent.com/EcoForecast/EF\_Activities/master/data/gflu\_data.txt",skip=11)  
time = as.Date(gflu$Date)  
y = gflu$Massachusetts  
  
yobs = y[time > "2014-08-01"]  
tobs = time[time > "2014-08-01"]  
plot(tobs,yobs)

 Create various visualizations to assess model performance as per the suggestions in Dietz, chapter 16. As a minimum, (1) plot the mean model output along with the observed cases vs time, (2) plot observed vs predicted (mean) and compute the correlation , and (3) plot the residuals (observed less predicted) vs both time and predicted. Comment on the results.

1. (optional) Create visualizations and compute descriptive statistics to assess the model of [problem 2.5](probs-2-5) or any model used in any other problem sets in the school (I.e., pick your favourite model and assess it).

# Preparation for students with limited coding experience

Coding involves some knowledge of specific languages (for the summer school this is R), however the most important coding skill is having a good idea for how to do what you want to do (i.e., writing pseudo-code), having experience solving similar problems (the summer school aims to give you this experience for your own future research), and being skilled at debugging.

If you don’t feel confident with your coding, I recommend being open to learning from a fellow summer school participant that is strong at coding - this is how many of us learned.

If you want to learn more R functions, you can complete the [software carpentary](http://swcarpentry.github.io/r-novice-inflammation/aio.html) modules, or consult my [R guide](https://ahurford.github.io/quant-guide-all-courses/) (there are other similar guides that might be better), but I’m not sure this is necessary.

Debugging comes with experience, and it can help to view it as hypothesis testing. Chapters 3 and 4 of Dietze 2017 are not covered in the summer school, but this is some good content related to handling data and scientific computing.

The summer school involves a guest lecture from Steve Walker. If you are interested in best practices and learning coding, take the opportunity to ask Steve’s advice.

# Photos

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# Preparation for students with few previous math courses

[A Biologists Guide to Mathematical Modeling in Ecology and Evolution](https://press.princeton.edu/books/hardcover/9780691123448/a-biologists-guide-to-mathematical-modeling-in-ecology-and-evolution) by Sarah P. Otto and Troy provides an excellent introduction to the development and analysis of mathematical models. This textbook can be downloaded as an ebook from many university libraries.

For a student with few math courses, in preparing for the summer school, I would recommend:

* **Chapter 2. How to construct a model**. This is an excellent introduction to learning to make your own models. You should be able to solve Problems 2.1-2.6 and 2.8. Also, on this topic, you can read Chapter 1. of Keeling and Rohani, the text book for the Mathematical Epidemiology course at the summer school.
* **Chapter 3. Deriving Classic Models in Ecology and Evolutionary Biology**. Building your own models requires a working knowledge of the foundational models. You can omit 3.3. Problems 3.12-3.13.
* **Primer 1. Functions and approximation**. I wouldn’t read this section, but you should know that it is good reference material for understanding the shape of functions.
* **Chapter 5. Equilibria and stability of one variable models.** This is an important chapter, because ultimately you should have a mastery of Chapter 8, and Chapter 5 is foundational in that progression. The summer school models will mostly be continuous time, (also referred to as differential equations) rather than discrete time, , (also referred to as recursion or difference equations), so if you are time-limited focus on understanding equilibrium and stability for continuous time models. Problems: 6.4a-c, 6.6, 6.8b-d, 6.9.
* **Primer 2 Linear Algebra** Again, I wouldn’t read this, but as we consider multivariable models, if you find yourself struggling, it could be necessary to study this chapter on linear algebra.
* **Chapter 7. Equilibria and stablity analysis - linear models with multiple variables.** Epidemiological models, generally, will not be linear ordinary differential equations, but nonetheless, understanding linear differential equation models is foundational to understanding non-linear models (the type that appears in the mathematical epidemiology literature). Furthermore, most non-linear models are approximated well by linear models given some restrictive assumptions. While no one desires to unnecessarily make restrictive assumptions, linear models have general solutions (details are given in Chapters 6 and 9), and that aspect of linear models is sometimes very powerful, such that linear models can be useful even if your results hold only under restrictive assumptions. Again, you want to focus your reading on continous time models. You should work towards being able to solve Problem 7.3.
* **Chapter 8 Equilibria and Stability Analysis - nonlinear models with multiple variables**. 8.1, 8.2 and 8.5 only. Problems: 8.1, 8.4a-c, 8.12.

Learning mathematics requires giving yourself the time to read and think, but it is also very necessary to practice solving problems to make sure you fully understand what is written.

# Problems 2.3. Characterizing uncertainty

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# Problems 2.4. State-space models & fusing data

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# Problems 2.5. Propagating uncertainty

Placeholder

# Problems 2.8 Modeling for decision support

1. In a group of 3 to 4, work together to make a consequence table related to the implementation of capacity limits and/or social distancing in retail, schools, and community recreation venues during a pandemic due to an airborne respiratory illness. Have each group member play the role of a different stakeholder. Do not do the modelling to determine the values in the consequence table, instead represent these as values, .
   * Write a paragraph describing how you applied some of the principles described in Chapter 17 of Dietze.
   * Provide any inequalities related to the values, , you expect in the consequence table. Describe the trade-offs the consequence table reveals.
   * Provide a simple epidemiological model that might form the deterministic skeleton for a model that could be used to estimate the values in the consequence table.
2. Write 1 paragraph, which is an example of something that in hindsight was a “failure in imagination” during the COVID-19 pandemic.
3. Describe how a mathematical model (preferably with equations) could be extended to consider the “failure in imagination” that you described in 2.
4. Visit <https://www.ipcc.ch/report/ar6/wg2/>. Find a figure of future carbon emission scenarios (Reconstruction Concentration Pathways (RCPs)), and their impacts. Write a paragraph that describes how the presentation of projections in the IPCC report are consistent with the principles discussed in Chapter 17 of Dietze (2017) for scenario construction.

# Congenital syphilis

Skyrocketing rates of congenital syphilis (see [here](https://www.cbc.ca/news/health/syphilis-cases-in-babies-skyrocket-in-canada-amid-health-care-failures-1.6797257), and [here](https://www.canada.ca/en/public-health/services/reports-publications/canada-communicable-disease-report-ccdr/monthly-issue/2022-48/issue-11-12-november-december-2022/infectious-congenital-syphilis-canada-2021.html) lead to severe and lifelong complications in newborn babies born to infected mothers. Congenital syphilis is currently a public health crisis in Canada. Develop a mathematical model for congenital syphilis in Canada. How might access to earlier testing and treatment in pregnancy help to reduce congenital syphilis in Canada?

# Antimicrobial-resistant Gonorrhea

We are facing the very real possibility that gonorrhoea infections are going to become untreatable in the not so distant [future](https://www.ctvnews.ca/health/highly-resistant-gonorrhea-on-the-rise-in-canada-other-countries-world-health-organization-1.6492406). Antimicrobial resistance (AMR) is making gonorrhoea infections more and more difficult to treat. Previous research has shown that an important consideration for modelling gonorrhoea is the role of a “core group” (a group of individuals who have much higher contact rates than the rest of the population) (see: [here](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4760416/)). At the same time, some new research suggests that doxycycline PEP (post-exposure prophylaxis with doxycycline (within 3 days) after unprotected sex in men who have sex with men (MSM) and transgender women is very effective. However, it seems like increased use of doxy-PEP could further contribute to increasing antimicrobial resistance. Develop a model to answer the following question: Under what conditions do you think that introducing doxy-PREP into the public health toolbox for this population will or will not contribute to AMR?

# Porcine epidemic diarrhea virus

Porcine epidemic diarrhea virus (PEDv) is a coronavirus that infects pigs causing severe disease and mortality in young piglets but less severe disease in adult pigs. PEDv does not transmit to humans and is also not transmissible to humans via food (so it is not a food-borne disease risk). PEDv is an economically important disease for agriculture. ransmission is predominantly fecal-oral and infected pigs shed large amounts of virus into their environment during the course of their infection which creates an environmental reservoir of the pathogen which can infected other animals. While a vaccine against PEDv has been used outside of Canada and has been shown to reduce both morbidity and mortality, the Canadian PEDv is a newly emerged strain for which there is no vaccine available at this time. However, new vaccine trials have shown that the PEDv vaccine in development seems to [enhance disease symptoms and virus replication in vaccinated individuals](https://www.nature.com/articles/s41541-021-00283-x). Do you think that it would be possible to control the spread of PEDv on a farm using biosecurity measures alone (so relying on things like cleaning etc.)? Under what circumstances?

# Behaviour change in an epidemic

Behaviour change can include social distancing uptake, wearing masks, etc (these are also called non-pharmaceutical interventions (NPI)). NPIs can help to curb an epidemic/pandemic (i.e., flatten the curve), but behaviour change can wane over time, with pandemic fatigue, and uptake of NPI later in an epidemic can be difficult to induce in a fatigued population. Develop a mathematical model of behaviour change with fatigue. Show that fatigue can induce multiple waves of infection. How can government combat fatigue? Consider the effects of mass media messaging in changing behaviour.

For more background on the topic see the [this Science Table brief](https://covid19-sciencetable.ca/wp-content/uploads/2021/04/Science-Brief_Enhancing-Adherence-to-Public-Health-Measures_20210422_published.pdf).

# Investigating the conditions for locally transmitted dengue infections

One of the consequences of climate change is a modification of the range of many species. One preoccupying such change is the northward expansion of the range of *Aedes aegypti* and *Aedes albopictus*, two of the vectors of *dengue*. This has resulted in a shift, in regions where dengue was absent, from no epidemics to micro-epidemics, where one infected individual returning from a region where dengue is endemic infects several individuals in close proximity, to more sustained epidemics. The same is true with *Chikungunya* and might become true, in the not so distant future, with *malaria*.

First, gather some information about this phenomenon and document a few instances where this occurred. Then, keeping this general framework in mind, write a mathematical model to describe the problem. The model will need to incorporate: - Temperature-dependent vector density, of a form you will need to determine so that vector abundances increase with one or two degree (C) of mean temperature increase. - A host population mostly naive to the pathogen. - Point introductions of the pathogen in the host population.

The main question to investigate is the transition from no local epidemics to micro-epidemics to sustained local epidemics.

Some ideas you may find useful: - While formulating and analysing the model in ODE is probably a good idea to get a sense of the general behaviour of the system, there is a lot to be gained by considering the continuous time Markov chain analogue. - One could even think of simulating the problem using ABMs or network models. Early outbreaks in the southern USA were often of nearby households, this could be fun to look at.

# Simulating the global spread of SARS-CoV-2

Write an ODE metapopulation-type model to describe the global spread of a pathogen like SARS-CoV-2 between countries. You should proceed to the basic mathematical analysis of the model, in order to understand well how model parameters are likely to affect model behaviour.

You will need to decide on the type of model to use: SIR, SLIR (a.k.a. SEIR), SLIAR or something else. You will also need to decide on whether to use an epidemic or an endemic model. Justify your choices.

Then simulate the model with, depending on your computational resources, either a continent or the entire world. Work at the country level. Learn how to pull data regarding country population (see, e.g., [this paper](https://doi.org/10.1016/j.idm.2019.12.008) and its associated [github repo](https://github.com/julien-arino/modelling-with-data)), in order to construct movement using gravity-type weights. (You will also need to find *country centroids* to incorporate distances between countries.)

Compare the rate of *country invasions* you obtain (i.e., the number of countries reporting case counts larger than some detection threshold that you will choose) with that observed in real life (see, e.g., Figure 1 [here](https://julien-arino.github.io/assets/pdf/papers/2022_Arino-FIC85.pdf)).

Then modify your model to incorporate travel restrictions, both global (acting on all movement rates at the same time) or local (acting on some movement rates).

It could be interesting to consider also the continuous time Markov chain analogue of your model. You could also consider a network model.

# Leprosy and Biological Invasion

Armadillos can carry leprosy. With climate change, feasible habitats for armadillos can expand. Thus, areas where leprosy cases are rare can experience increases in leprosy incidence. Develop a mathematical model of armadillo movement with climate change and project the effects of armadillos on leprosy incidence in space.

For more background, see [this article in USA Today](http://www.digtriad.com/news/article/282114/175/Armadillos-Invading-East-Tennessee) or since that link is dead, [this article](https://www.wbir.com/article/news/local/armadillos-spread-in-east-tn-surround-smokies/51-586333092).

# A guide for infectious disease models aimed to provide decision support

The aspects of decision support that we considered in the *Data, Models, and Decision support* course were based on structured decision making as described in the textbook with the same name by R. Gregory and L. Failing. Gregory and Failing’s book focuses on environmental management choices, however, best practices in decision support are also pervasive in the medical literature. Perform a systematic literature review to understand the differences and overlap between the principles of decision support that are discussed in the environmental versus epidemiological literatures.

Perform a literature review to identify infectious disease modelling publications that you consider useful for decision support. Discuss how these publications conform to the principles of structured decision making discussed in Chapter 17 of *Ecological Forecasting*. Describe any new ideas these publications present for how to best do mathematical modelling to support decision making.

Find an infectious disease model in the literature that has results that could be reformulated to better conform to the principles of structured decision making. Reproduce the infectious disease model and present the results as a consequence table, and/or calculate quantities (i.e., utility, exceedence probability, the Pareto front, etc) that are mentioned in Chapter 17 of *Ecological Forecasting*.

You do not have to do all of these elements, however, please keep in mind that this is a math summer school, so you need to include an infectious disease model.

# Forecasting sampled tick abundance

Visit the NEON Ecological Forecasting Initiative web site and develop a model to forecast sampled [tick abundance](https://projects.ecoforecast.org/neon4cast-docs/Ticks.html) by following the instructions for the challenge. Note that this challenge occurred in 2021.

Your model needs to include a complete written description of the model you develop.

# *Dicrocoelium dendriticum* and the Zombie Ants

The Lancet Fluke (*Dicrocoelium dendriticum*) is an intestinal parasite of Sheep of some concern in Atlantic Canada <https://www.gov.nl.ca/ffa/files/agrifoods-animals-health-pdf-vs-02-001.pdf>

Research the life cycle of the parasite and its impact on sheep farming. Develop a model forecasting the spread of the parasite through a flock or over a region with the aim of forecasting some aspect of its impact on farming.

Your report should include a discussion of your assumptions about the sources uncertainty in your forecast. One option is to focus on issues of data collection and process variability, another is to focus on the complex dynamics (e.g., a bifurcation analysis) and their role in forecast uncertainty.

# Preparation for students with few stats courses

The statistics covered in the Data, Models, and Decision support course focuses on bridging dynamical system models, such as those covered in Keeling and Rohani, with data. There is also an emphasis on mechanistically describing sources of uncertainty in model predictions.

The topics covered in this course are statistical in nature, but the motivation and presentation is quite different from statistics courses.

To prepare for the summer school, if you are inexperienced with statistics, I recommend revisiting some basic probability. For this you can read Primer 3 in *A Biologists Guide to Mathematical Modeling* by Sarah P. Otto and Troy Day. In addition, while it will be covered at the summer school, it might help to read Chapter 5. Introduction to Bayes in the *Ecological forecasting* book by Michael Dietze.

Both these books are usually available for download as ebooks from university libraries.