Webinar: Costs and Benefits of Defending against Viral Infection: Lessons from Natural Ecosystems

Presented by:
Professor David Talmy
National Institute for Mathematical and Biological Synthesis, University of Tennessee, Knoxville

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MEET YOUR MODERATOR

Louis J. Gross, PhD

Director, National Institute for Mathematical and Biological Synthesis (NIMBioS)

Director, The Institute for Environmental Modeling, University of Tennessee

Chancellor’s Professor of Ecology and Evolutionary Biology and Mathematics, University of Tennessee
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**Upcoming Webinars**

*Modeling for a Globally Connected World: What Models are Good for and How they Work*

**Date:** 3:30 EDT Tuesday, April 14, 2020

**Speaker:** Dr. Louis Gross, NIMBioS Director and Chancellor's Professor of Ecology and Evolutionary Biology and Mathematics at the University of Tennessee

**Moderator:** Dr. Suzanne Lenhart, NIMBioS Associate Director and Chancellor's Professor of Mathematics at the University of Tennessee

**Abstract:** Policies for the COVID-19 pandemic response have relied upon models of various types to project future trends and assess the potential impacts of alternative amelioration strategies. I invite you to join us for basic overviews of the process of modeling, the “art” of model construction, and the array of different kinds of approaches (mathematical, computational, and graphical) that are applied in the life sciences. The presentation is designed for a general audience without modeling background.

A recording of each webinar will be posted
MEET YOUR PRESENTER

David Talmy, PhD

Assistant Professor of Microbiology, University of Tennessee

Adjunct Assistant Professor of Ecology and Evolutionary Biology, University of Tennessee
Costs and Benefits of defending against viral infection: Lessons from nature

1) Viruses are extremely widespread in nature
2) All living organisms must balance the costs and benefits of defending against viral predation
3) Balancing costs and benefits of defending against viral infection has profoundly influenced natural ecosystems
False color chlorophyll from SeaWiFS satellite (https://svs.gsfc.nasa.gov/3450)
Plankton such as the coccolithophore *Emiliania huxleyi* have shaped Earth

- Photosynthetic single-celled organism
- Abundant in the surface ocean
- Forms calcium carbonate ‘coccoliths’ (disks on surface)

5 µm (5 millionths of a meter)
(5 thousandths of a mm)
Calcium carbonate (often from coccoliths) is widespread in the modern ocean.
EhV (Emiliania huxleyi Virus) and other predators Infect and kill *E. huxleyi*

Heavy calcium carbonate in the outer shell sinks to the seafloor
Are there ‘outbreaks’ of viruses throughout the oceans?

https://svs.gsfc.nasa.gov/30512
Norwegian Fjord near Bergen is a great place to study *E. huxleyi*
Mesocosm
(‘middle-world’)

Study *E. huxleyi* and their viruses in nature

https://fjordphytoplankton.wordpress.com
Are there ‘outbreaks’ of viruses throughout the oceans?

https://svs.gsfc.nasa.gov/30512
A virus ‘outbreak’ in a Norwegian Fjord...
Are there ‘outbreaks’ of viruses throughout the oceans?

https://svs.gsfc.nasa.gov/30512
Models are tools that can be used to understand how widespread virus infection is in the ocean.

“Real world”

Math

\[ \frac{dR}{dt} = \frac{S_R}{H} - aRH \]

\[ \frac{dH}{dt} = aRH - bHV \]

\[ \frac{dV}{dt} = bHV - cV \]

Modeling

(math meets “real world”)

???
Models can be thought of as scientific hypotheses

“Real world”

Math

Model A vs. model B

Modeling
(math meets “real world”)
Two models of virus infection in the ocean

- Model A: “Epidemics are everywhere”
- Model B: Nature “flattens the curve”

These models can be tested with data
All organisms feed on resources and resist predation

Model A: “Epidemics are everywhere”
Simplest model of resource-producer-consumer

- **Beginning**
- **Middle**
- **End**
Beginning

Resource → Host → Virus
Simplest model of resource-producer-consumer

Beginning

Middle

End
Resource → Host → Virus
Simplest model of resource-producer-consumer

Beginning

Middle

End
Models can be thought of as scientific hypotheses

Model A: “epidemics are everywhere”
Model A Equations

\[
\frac{dR}{dt} = S_R - \alpha RH \\
\text{resource inflow} - \text{resource utilization}
\]

\[
\frac{dH}{dt} = \alpha RH - \phi HV \\
\text{resource utilization} - \text{infection}
\]

\[
\frac{dV}{dt} = \beta \phi HV - \delta^2 V \\
\text{infection} - \text{viral death}
\]
Models can be thought of as scientific hypotheses

Model A: “epidemics are everywhere”

Model B: Nature “flattens the curve”
Model A: With meerkats, scorpions, and eagles

"Producer"

"Resource"

"Consumer"
Model A: With meerkats, scorpions, and eagles

“Producer”

“Resource”

“Consumer”
Model A: With meerkats, scorpions, and eagles
Model B: Nature “flattens the curve”

“Producer”

“Resource”

“Consumer”
Model B: Nature “flattens the curve”

“Resource”

“Producer”

“Consumer”

“Defensive producer”
Model B: Nature “flattens the curve”

“Resource” — “Producer” — “Consumer” — “Defensive producer”
Model B: Nature “flattens the curve”

“Producer”

“Resource”

“Consumer”

“Defensive producer”
Model B: Nature “flattens the curve”

“Producer”

“Resource”

“Consumer”

“Defensive producer”
Alternative hypothesis: defensive behaviors inhibit many “outbreaks” from happening
Alternative hypothesis: defensive behaviors inhibit many “outbreaks” from happening.
Balancing costs and benefits of defending against predation has shaped ecosystems.
Model B Equations

\[
\frac{dR}{dt} = S_R - \alpha R H \\
\frac{dH}{dt} = \alpha R H - \phi H V \\
\frac{dV}{dt} = \beta \phi H V - \delta^2 V
\]

\[\log(\alpha) + \log \left(\frac{1}{\phi}\right) = \text{Constant}\]
Models can be thought of as scientific hypotheses

Model A: “epidemics are everywhere”

Model B: shifting resource allocation “flattens the curve”
Models can be thought of as scientific hypotheses

Model A: 
“epidemics are everywhere”

Model B: 
Nature “flattens the curve”
Models can be thought of as scientific hypotheses

Model A: “epidemics are everywhere”

Model B: shifting resource allocation “flattens the curve”
Models can be thought of as scientific hypotheses

“Real world”

Math

Model A

Model B

???
Sampling locations of microbes and viruses all over the world

Wigington et al., 2016
Models can be thought of as scientific hypotheses

“Real world”

Math

Model A

Model B
Model A vs. model B

Model A

Data

Model B

Balancing costs and benefits of defending against predation has shaped ecosystems.
Balancing costs and benefits of defending against predation has shaped ecosystems

- Resource
- Prochlorococcus
- Emiliana huxleyi
- Consumer
Adaptations to defend against ‘outbreaks’ may have had a lasting influence on Earth.

Particulate Inorganic Carbon (PIC)  https://svs.gsfc.nasa.gov/30512
Links between viruses, *E. huxleyi*, and the White Cliffs of Dover can be understood with models
Summary

- Mathematical models are a useful way to understand the ‘rules’ that control when virus ‘outbreaks’ happen in nature.

- Nature may have ‘flattened the curve’ in diverse ways.

- Defending against viruses and other predators has shaped ecosystems and Earth.
Thank you for your participation!

Questions? Please use the Question button on Zoom to post these