New Mathematical Methods for Complex System in Ecology: Summary and Outlook

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Why do we need new math methods in ecology?

- Environmental problems are becoming more difficult and are now more pressing
  - Global climate change
  - Environmental degradation
  - Invasive species
  - Overfishing
  - Emerging diseases
  - …

Why do we need new math methods in ecology?

- We are getting much more data and we need models (and math) to try to make sense out of it.
  - Satellite tracking
  - Drones
  - New genetic methods (eg, bar coding)

Why do we need new math methods in ecology?

- There are many key problems we are only just starting to solve and we now need new and improved methods
  - Full characterization of transient dynamics
  - Robust theory of how to connect dynamical models to ecology and fit the models to data
  - Tipping points arising from environmental change
  - Dynamical systems with intermediate levels of noise
  - The list goes on…

Why do we need new math methods in ecology?

We need new theoretical and computational frameworks to understand the problems and to connect to data

- Structural sensitivity (Andrew)
- Tipping points, critical transitions and factors that affect them (Sebastian W, Christian)
- ”Stability” of ecological states under stochasticity (Karen)
- Impact of stochasticity on structured populations (Sebastian S)
- Optimal responses to complex environmental problems, and how to incorporate data (Suzanne)

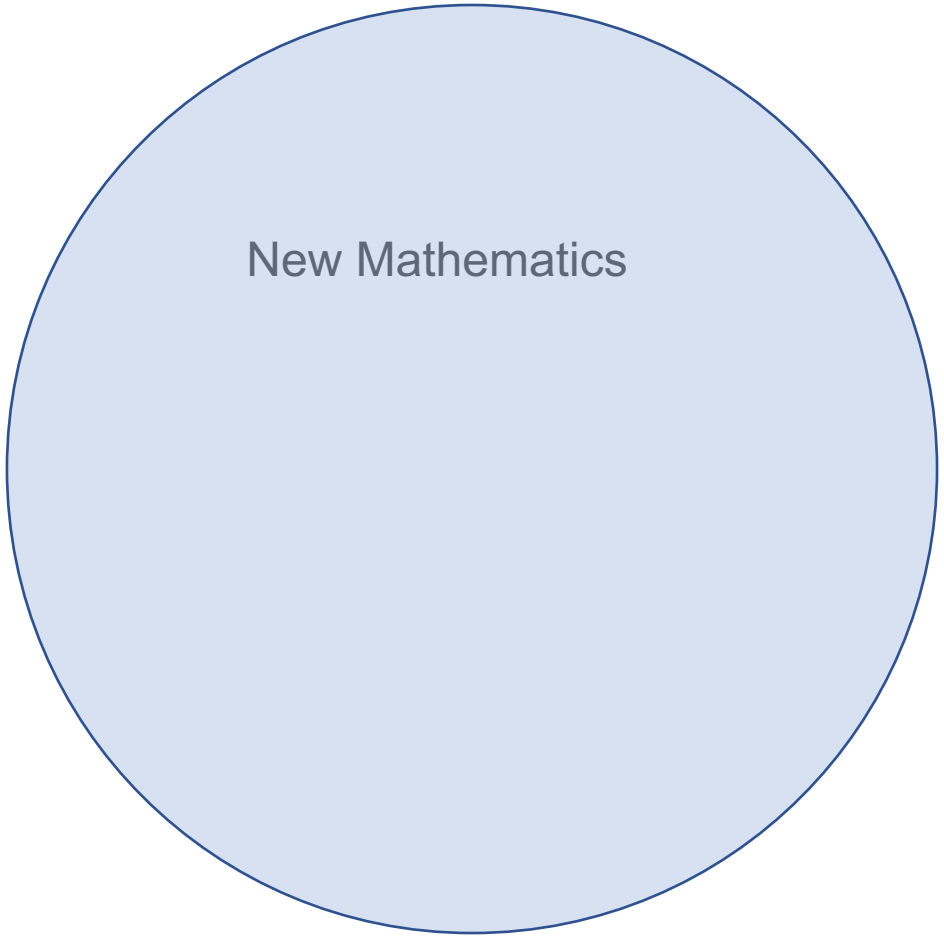
Why do we need new math methods in ecology?

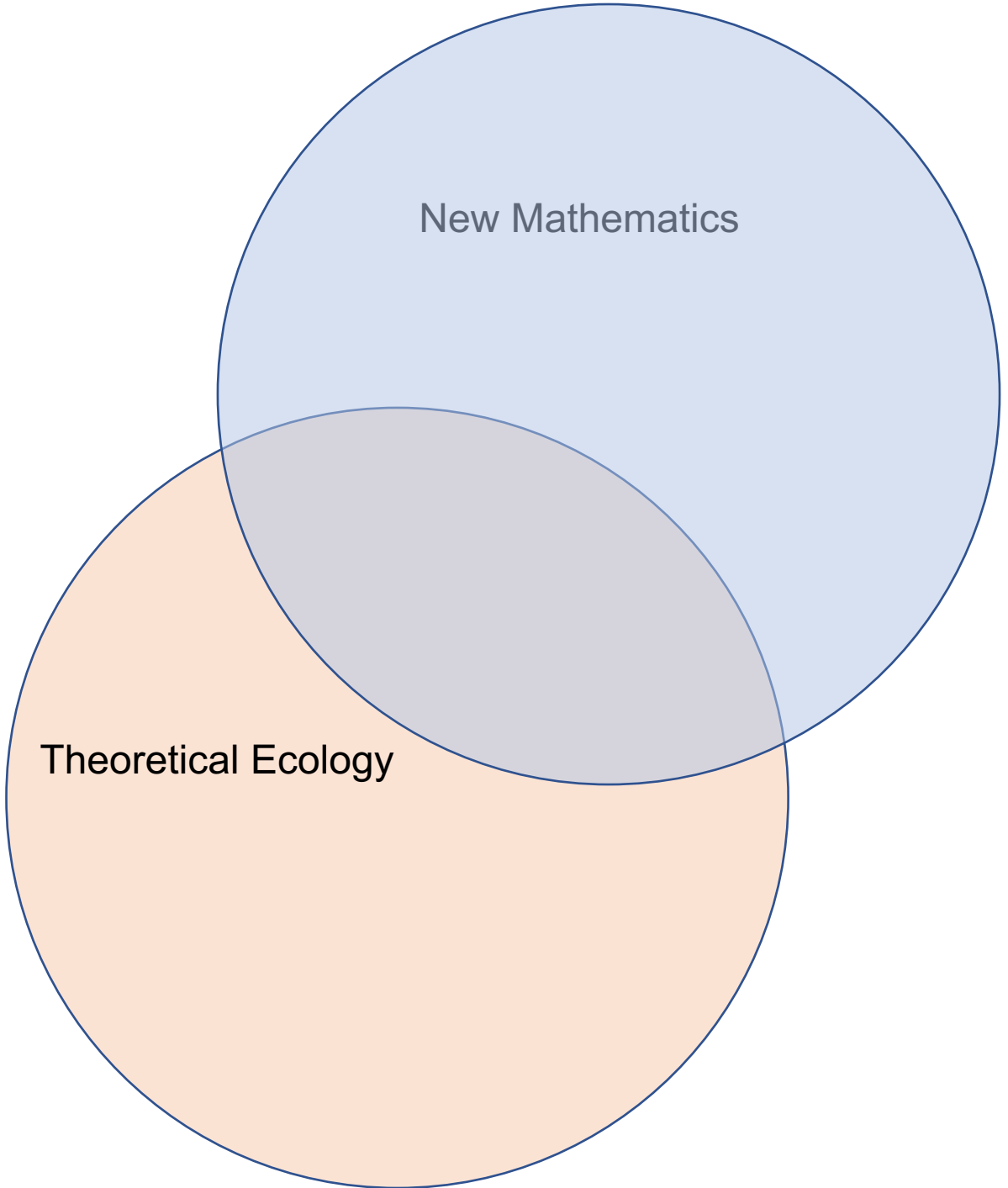
We need new theoretical and computational frameworks to understand the problems and to connect to data

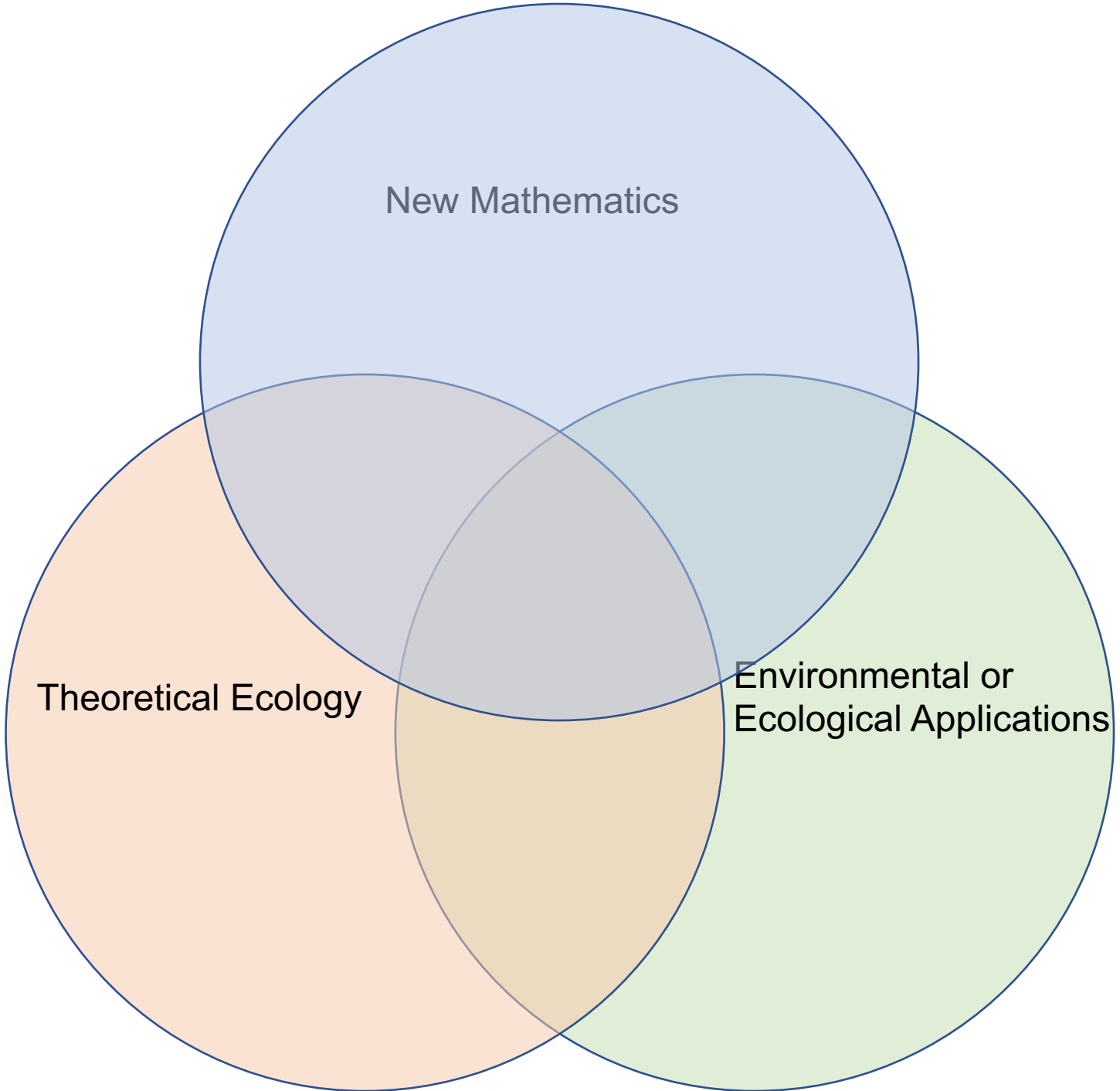
- How to fit complex models to data with observation error and make biological or management inferences (Steve, Natalia, Rebecca)
- Evolution in spatial systems (Chris)
- Unexpected complex nonlinear outcomes from simple models (Bob)
- Transient dynamics (Frithjof, Sergei, Susmita)
- Ecosystem functioning under stressful conditions (Ehud)
- Early warning metrics (Vasilis)

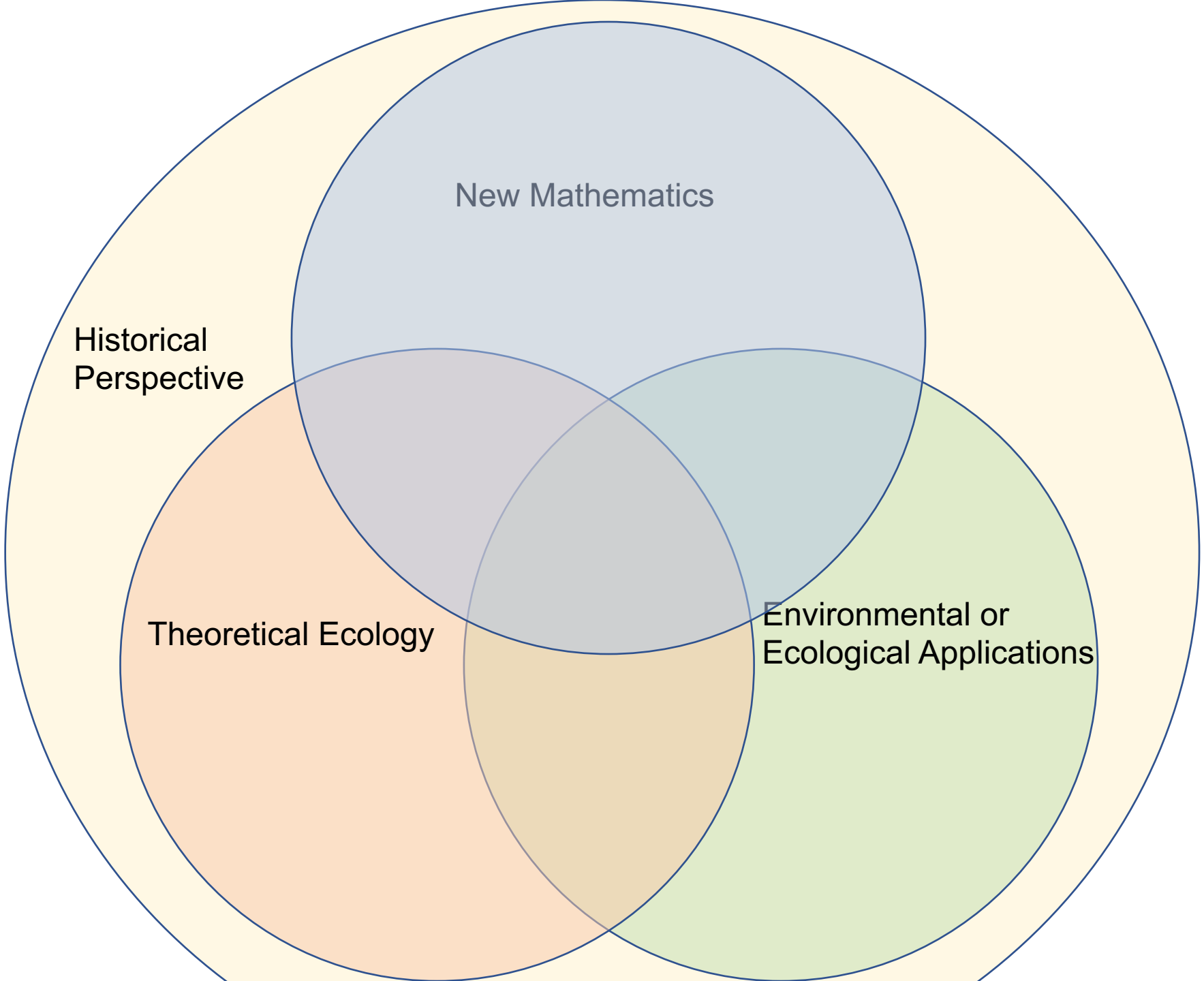
Why do we need new math methods in ecology?

- Mathematical methods developed for ecology have “spin-off” effects and synergies on mathematics
  - There is a long history of challenging math ecology problems giving rise to new mathematics
  - We need to develop new math based on the ecology in addition to borrowing old math


New Mathematics


New Mathematics
Theoretical Ecology


New Mathematics
Theoretical Ecology
Environmental or
Ecological Applications


New Mathematics
Historical
Perspective
Theoretical Ecology
Environmental or
Ecological Applications

Recurring themes involving New Mathematics

- Nonlinear dynamical systems
- Multiple time scales
- Bifurcation analysis/energy potentials
- Stochastic processes
- Inference/data analysis methods
- Perturbed dynamics (ranging from one-time to continual)
- Meta-analysis
- Optimization and control
- Spatial complexities
- Other?

What are key advances in Theoretical Ecology coming from new math?

- A theory for tipping points for ecological systems
- A theory for transients for ecological systems
- A new understanding of the roles of sensitivity (structural and parameter) and identifiability (structural and applied) in determining which questions we can reasonably answer
- Ecosystem management and decision making
- Other?

What are some key Environmental or Ecological Applications for the new math?

- Predicting effect of environmental change on ecological dynamics (non-stationary)
- Enhanced environmental forecasting for populations (eg., fisheries)
- Feedback between ecology and management (human-environment systems)
- Methods for ecological data analysis
- Other?

What are some of the biggest Mathematical Gaps that we could fill in?

- Intermediate asymptotics for stochastic processes (non-ergodic) and the possibility of long-term transient dynamics
- Extending “r-tipping” theory to more complex systems (eg, predator-prey, spatial problems via PDEs and so on)
- A more complete theory for model sensitivity for inverse problems
- A more complete theory of parameter identifiability for dynamical systems
- Further development of methods for analysis of transient dynamics
- Dynamical systems on complex networks
- Other?

Are there some questions that it doesn't make sense to try to try answer?

- Mathematical analysis of structural sensitivity can help us determine which these questions might be.
- Mathematically showing what you cannot do could be as useful as showing what you can
- A solution might lie in either reformulating questions or possibly by applying nonparametric models
- Other approaches?

Questions/Comments?

Thank you on behalf of the organizers: Andrew, Alan and Mark

- It has been a fun week
- You have made it really easy for us to be organizers
- Thanks to BIRS for a great set up, great food (and great weather!)
- BIRS also supports Focused Research Groups (up to 8 people) for periods of one to two weeks
- If you would like to, please email your workshop comments/testimonial to birs@birs.ca