Mathematics of Human Environmental Systems

Mark Lewis (University of Alberta),
Yoh Iwasa (Kwansei Gakuin University),
Simon Levin (Princeton University),
Pauline van den Driessche (University of Victoria)

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1 Overview of the Field

This workshop addressed emerging challenges in human-environment interactions. Ecosystem services are under threat due to human activities. The workshop focused on modelling feedbacks between the environment and human behaviour with a view to illuminating the mathematical structures that govern interactions. The workshop goal was to develop methods that can suggest a path forward in improving the interactions between humans and the environment.

2 Recent Developments and Open Problems

The mathematical modelling of human-environmental systems is an emerging area in mathematics, employing a mixture of dynamical systems, stochastic processes, and agent-based models, coupled to optimization, control or multiplayer games.. Key areas of scientific focus include:

- Human behaviour and incentives in models for vaccination and control of disease spread.
- Feedback structures for improving land use and food security.
- Coupled social-economic influences on ecological dynamics from lake pollution to illegal logging
- How to manage for resilience in human-ecological systems.
- Sustainable development and social welfare.
- Adaptive management and regulation of forestry, rangeland and fisheries resources.

3 Presentation Highlights

The meeting started with an overview of how game theory and ecological models can be coupled to understand human behaviour in the context of environmental issues and environmental degradation. Yoh Iwasa addressed the issue of persistence of corruption and illegal logging, showing how incentives and profit sharing can be used to reduce corruption and lead to improved outcomes. Chris Heggerud discussed the coupling of ecologically harmful blue-green algae dynamics in lakes to human agro-ecosystems. This kind of system exhibits multiple stable states and hysteresis. He included the role of incentives and opinion dynamics on transitioning from outbreak to endemic states for the blue-green algae blooms.

Continuing on the theme of coupled ecological-human systems, on Tuesday Frank Hilker addressed the two fundamentally different approaches to model human responses. His application was lake eutrophication, and the different response dynamics were best response dynamics and replicator dynamics. These gave rise different outcomes (eg, saddle-node bifurcations versus limit cycle dynamics). His talk emphasised how subtly different assumptions about behaviour can lead to very different outcomes. Mayuko Nakamura focused

on a specific case of sustainable harvesters in socio-ecological systems: swiftlets in Malaysia. These birds are used for traditional Chinese soups. Using stage-structured dynamics for the birds and detailed property rights systems, she showed how sustainable harvesters could actually obtain better returns than unsustainable harvesters in the short term. The final lecture of the day connected back to the subject of forest-human interactions introduced by Yoh Iwasa, where Akiko Satake showed how deforestation could be modelled via dynamical systems with coupled social and ecological components.

The coupled ecological-human systems theme was rounded out by four additional talks. On Thursday Alan Hastings discussed the role of transients in human-environmental systems. These play an increasingly important role in our mathematical understanding of ecological dynamics. His talk emphasized dynamics near tipping points as a rich area of study with many new results. However, he also showed that even linear systems can provide a wide array of transient dynamics, which can be used to understand significant ecological problems, such as the recovery of marine reserves after the cessation of fishing. Chris Bauch continued this theme, focussing on methods for AI and machine learning and data science that can be used to predict critical transitions. The impact of environmental forecasting on human-environmental dynamics was the subject of the following talk by Andrew Tilman. He showed how feedback loops can lead to persistent cyclical environmental overshoots and proposed feedback methods to improve the stability of the feedback loops. Finally, on Thursday afternoon Nina Fefferman presented modelling insight regarding the role of humans as ecosystem engineers of the pathogen landscape.

Another key theme of the meeting was the interplay between human behaviour and epidemiology. On the first day, Eli Fenichel discussed lessons learned about coupling human-epidemiological modelling, particularly in the context of COVID-19 dynamics. The concepts of epidemiology can be applied outside the immediate spread of infectious disease. Rebecca Tyson presented research on how coupled human and natural systems (CHANS) can be used to understand changes in opinion dynamics (viewed from an epidemiological perspective) over time. The subject of epidemiology was revisited on Thursday afternoon where Junling Ma presented his work on disease dynamics on networks and David Finnoff provided an economists perspective on how to couple epidemiology with economic theory.

The final day of the meeting involved more broad-ranging talks on how mathematics of human environmental systems can illuminate some of the most important environmental questions of our time, ranging from climate change behaviour and mitigation (Madhur Anand and Lou Gross) to food security (Hans Kaper).

4 Scientific Progress Made

The meeting provided a broad overview of emerging problems in the area of human-environmental interactions. There was a very strong synergy between the problems and new mathematical methods. While the underlying ecological and environmental dynamics are well-modelled by dynamical systems, stochastic processes, and agent-based models, the human-environment problems all have an element of either optimization, control or multiplayer games. Mathematically the meeting focused on the interaction between dynamical systems and related models with the theory of optimization, control, games and adaptive dynamics.

5 Outcome of the Meeting

The workshop structure provided time for much informal discussion, including some additional presentations, for example, by Mary Lou Zeeman on her research on the categorization and analysis of transient dynamics in linear systems. Throughout the meeting, the discussion made clear how the area of coupled human-environmental systems is very new and presents many exciting possibilities for further research. Although the workshop was entirely online, the participation was restricted mainly to invited participants. This created a very open dynamic for discussion sessions with many new ideas for future research. We thank BIRS for hosting this workshop, and for well facilitating the electronic delivery.