PIMS Collaborative Research Group

# Mathematical Ecology and Evolution

April 1, 2003 – March 31, 2006

**Thomas Hillen**
University of Alberta

## 1. INTRODUCTION

As the current revolution in biological information progresses, there is a well recognized need for new quantitative approaches and methods to solve problems in ecology. One challenge is to model complex ecological systems--systems that depend upon a myriad of inputs, but often with incomplete details regarding the inputs. Such systems range from spatial disease dynamics (e.g., influenza, tuberculosis, West Nile Virus) to the responses of biota to global environmental change (e.g., vegetation shifts, invaders into lake ecosystems, stream ecosystems), to the impacts of habitat fragmentation on species survival (biodiversity). Mathematical tools for addressing such biological problems include stochastic processes, nonlinear dynamical systems, adaptive dynamics, scaling methods from individuals to populations, statistical inference, and computational methods.

Research in any interdisciplinary field brings its own particular set of challenges: (i) The rigorous and unambiguous aspects of mathematics versus the overwhelming complexity of the biological world. (ii) The different languages of mathematics and biology that can provide a major barrier to interdisciplinary research. With this in mind, an interdisciplinary research program that significantly impacts both mathematics and biology has some basic requirements: (i) the opportunity for training outside the core discipline of mathematics or biology, and (ii) a mechanism for effective collaborations and cross-communication between empiricists and theoreticians.

The collaboration between mathematicians and ecologists were central to the training of personnel in this research plan. This is expressed through the summer workshops at the University of Alberta for undergraduate students, a BIRS retreat for graduate students, a workshop and summer school for graduate students, a regular seminar series in mathematical biology, the hiring of three postdoctoral fellows (PDFs) in interdisciplinary research projects and the manifold involvement of students in research activities.

## 2. SUMMARY OF THE CRG ACTIVITIES

The benefits of the PIMS-sponsored CRG have exceeded our expectations. From the very beginning of this CRG we have involved as many PIMS-University research groups as possible. For example, the workshops, the BIRS meetings and an international conference in Nanaimo always included organizers and participants from other PIMS Universities. Through our association with PIMS and the CRG we were able to attract internationally recognized experts in Mathematical Biology to give talks at PIMS institutions, attend BIRS meetings, and collaborate with CRG researchers. Distinguished visitors, such as Roger Nisbet (Santa Barbara), Bryan Sleeman (Leeds) and Brian Grenfell (Cambridge/Pennsylvania State) gave a series of lectures at U. Alberta, UBC and U. Calgary.

Interaction between PIMS sites was particularly demonstrated through three shared PDF positions. Frithjof Lutscher worked with Ed McCauley (U. Calgary) and with Mark Lewis (U. Alberta) on a topic related to the modeling of river-ecosystems. Joanna Renclawowicz worked with Pauline van den Driessche (U. Victoria) and with Mark Lewis (U. Alberta) on the modeling of West Nile Virus; and she worked with Thomas Hillen (U. Alberta) on problems related to chemotaxis modeling. Mario Pineda-Krch worked with Michael Doebeli on modeling of evolution and selection.

The support of the CRG enabled us to increase our educational efforts as well. We gave three summer workshops in mathematical biology for undergraduate students and a 2-day retreat for graduate students in Banff. The BIRS-retreat involved groups from Calgary, Seattle, Vancouver and Edmonton.

None of these research collaborations, workshops, retreats, or talks could have been done without PIMS support. And by hosting such successful events we believe the CRG has augmented PIMS' international reputation.

3. RESULTS AND IMPACT

Our primary goal was to develop and strengthen the synergistic interactions between mathematics and ecology within and between PIMS Universities. Considerable collaborations have been fostered between Universities of Victoria, Calgary, Alberta and British Columbia as a result of the PIMS-sponsored CRG.

Through the various CRG related activities a very strong collaboration between the groups of Ed McCauley (U. Calgary) and Mark Lewis (U. Alberta) has developed. Regular visits from McCauley in Edmonton and Lewis in Calgary initiated a collaboration, which was further strengthened by a shared PDF, Frithjof Lutscher. F. Lutscher has been instrumental in the continued exchange between these groups and the 2-day BIRS retreat provided a great opportunity for students from both groups to meet. Recently, Ed McCauley has become co-leader of a new Water Ingenuity Center supported from the Alberta Ingenuity Fund. This research center has a yearly budget of about $1.5 million. The involvement of PIMS through the CRG and McCauley's close collaboration with mathematicians at PIMS cites has been an important driving force for the establishment of the water center. Within this center mathematical modeling will be used to investigate and understand the overwhelming complexity of river ecosystems. The corresponding projects, which were supported by the CRG, will be continued within this water center.

Collaboration on a smaller scale developed between Michael Doebeli (UBC), Firthjof Lutscher (U. Calgary and U. Alberta) and Thomas Hillen (U. Alberta) on phenotype splitting, which is a keystone to explain the development of biodiversity. It turns out that the integro-differential equation models are mathematically very similar to other models that Lutscher and Hillen have studied previously. A productive collaboration has developed since.

The high involvement of Dr. Lutscher in the CRG activities gave him the necessary scientific maturity to obtain an assistant professor tenure track position at Ottawa University in 2005.

The CRG Mathematical Ecology and Evolution supported Mario Pineda-Krch during his PDF at UBC. Dr Pineda-Krch worked on developing a modeling framework for studying ecological and evolutionary dynamics of spatially structured communities. One particular goal of his work is to study dynamics in finite predator-prey populations, and in particular the phenomenon of evolutionary branching, i.e., the adaptive mechanisms generating evolutionary diversification using numerical simulations that were run on the computer clusters provided by WestGrid. He studied two main phenomena: The occurrence of predator-prey cycles due to demographic stochasticity, and evolutionary branching and phenotypic plasticity as alternative responses to disruptive selection.

The PDF Joanna Renclawowicz (U. Alberta) worked with Pauline van den Driessche (U. Victoria) and Mark Lewis (U. Alberta) on the spread of West Nile Virus. This very successful project led to new insight into the mechanism of the spread of this disease (see list of publications). They derived and analysed the first spatially explicit model for West-Nile Virus spread. In collaboration with Thomas Hillen (U. Alberta) we obtained some specific important results on existence and boundedness of solutions to a chemotaxis model that includes attractive and repulsive signals. This forms a valuable contribution to the mathematical theory of chemotaxis equations.

The CRG hosted two international meetings at BIRS (Banff, Alberta) and supported an international conferences on differential equations in mathematical biology in Nanaimo, BC.

The BIRS-meeting "Mathematical Biology: From Molecules to Ecosystems: The Legacy of Lee Segel" was organized by L. Keshet (UBC), S. Levin (Princeton), and M.A. Lewis (Alberta). In this workshop we explored a unifying common link that highlights how seemingly diverse areas of biological application are interwoven in the discipline, a theme that centers on the work and contributions of Lee Segel. Represented at this workshop were scientists across all ages (from graduate student to emeritus professors), with significant representation from both genders, and with a mixture of talks from novice and experts alike.

The BIRS focused research group on "Mathematical Models for Plant Dispersal" was organized by M. A. Lewis (Alberta),and J. Bullock (NERC Centre for Ecology and Hydrology, UK). The ability of plants to move into new environments and adapt to global change depends crucially upon the dispersal of the plant seeds. The importance of dispersal applies equally to invasive pest plants (many of which are extremely costly to agriculture), to persistence of threatened plants and species, and to the movement of indigenous plants, such as hemlock and spruce, in response to climate change. The meeting brought together mathematicians and quantitative biologists. This cross-disciplinary research environment led to specific advances in the modeling of plant dispersal. The focused research group comprised of J. Bullock (NERC, Dorset), D. Greene (Concordia), S. Higgins (UFZ, Leipzig), M. Lewis (Alberta), A. Pielaat (Alberta), T. Robbins (Utah), M. Soons (Utrecht), and O. Tackenberg (Regensburg).

The international conference on "Differential Equations and Applications in Mathematical Biology" at Malaspina University of Nanaimo, BC was partially supported by the CRG. It was organized by E. Braverman (Calgary), M. Li (Alberta), L. Idels (Nanaimo), L. Berezansky (Israel), A. Ponosov (Norway), and E. Litsyn (Israel). Represented at this conference were about 60 scientists from all over the world, including young and experienced researchers. Focus areas included applications of delay equations, modeling of aquatic ecosystems and modeling of epidemics.

Finally, our educational efforts (summer workshops in 2003, 2004, 2005, 2-day retreat in 2005, the seminar in mathematical biology 2003-06, and the visitor program) have been well-received and garnered excellent feedback. The summer workshops were held at University of Alberta and the course notes from these workshops have been published as a textbook with SIAM publishing (see references). Moreover, the PDFs and graduate students from U. Alberta were involved in the instruction process and they gained important experience in the teaching of mathematical biology. From about 60 students of our summer workshops we know that at least 15 have chosen mathematical biology as their area of graduate studies, most of them at PIMS Universities. As an example we cite two replies of undergraduate students of our summer workshops:

*There were two main benefits of the Workshop to me. First, it gave me some experience in modeling, which I had never done before. As well, it was a wonderful opportunity to meet students from across the country and gave me a broader perspective on my own education.*        *L.F.*

*I think the biggest thing I got out of the workshop was an appreciation of the wide variety of modeling applications (especially through the projects) - and also the immense power of a relatively limited set of techniques.  M.S.*

The PIMS Distinguished Visitors Bryan Grenfell and Roger Nisbet, and the Endowment Fund for the Future Distinguished Visitor Brian Sleeman all spent considerable time with students from the various PIMS Universities. In particular Brian Sleeman and a PhD student, Zhian Wang, worked on a problem related to hyperbolic partial differential equations and a paper has been submitted (see references). The PIMS travel fund was used to send graduate students to BIRS meetings which were held within the CRG. This presented a great opportunity for the students to learn about new methods and to meet scientists from all over the world.

## 4. MEMBERS

| Name | Department | Institution | Status |
| --- | --- | --- | --- |
| Michael Doebeli | Department of Zoology | | |
| | Department of Mathematics | UBC | Faculty |
| Eirikur Palsson | Department of Biological Sciences | SFU | Faculty |
| Bernard Roitberg | Department of Biological Sciences | SFU | Faculty |
| Mark Boyce | Department of Biological Sciences | U. Alberta | Faculty |
| Herb Freedman | Department of Math & Stat Sciences | U. Alberta | Faculty |
| Thomas Hillen | Department of Math & Stat Sciences | U. Alberta | Faculty |
| Subhash Lele | Department of Math & Stat Sciences | U. Alberta | Faculty |
| Mark Lewis | Department of Math & Stat. Sciences. and Biological Sciences | U. Alberta | Faculty |
| Michael Li | Department of Math & Stat Sciences | U. Alberta | Faculty |
| Jens Roland | Department of Biological Sciences | U. Alberta | Faculty |
| Joseph So | Department of Math & Stat Sciences | U. Alberta | Faculty |
| Edward McCauley | Department of Biological Sciences | U. Calgary | Faculty |
| James Anderson | School of Aquatic and Fishery Sciences | U. Washington | Faculty |
| Carl Bergstrom | Department of Biology | U. Washington | Faculty |
| Daniel Grunbaum | Department of Biology | U. Washington | Faculty |
| Ray Hilborne | School of Aquatic and Fishery Sciences | U. Washington | Faculty |
| Mark Kot | Department of Applied Mathematics | U. Washington | Faculty |
| P. van den Driessche | Department of Mathematics | U. Victoria | Faculty |

## 5. CRG-SUPPORTED POSTDOCS

Frithjof Lutscher (U. Alberta and U. Calgary), collaboration with E. McCauley (U.Calgary), M. Doebeli (UBC), M. Leiws (U. Alberta) and T. Hillen (U.Alberta). Since 2005 Assistant Professor at U. Ottawa.

Joanna Renclawowicz (U. Alberta and U. Victoria), collaboration with P. van den Driessche (U. Victoria), M. Lewis (U. Alberta), and T. Hillen (U. Alberta). Since 2004 Polish Academy of Sciences, Warsaw, Poland.

Mario Pineda-Krch (UBC), collaboration with M. Doebeli (UBC). Now at the Center for Animal Disease Modeling and Surveillance, University Of California, Davis.

## 6. STUDENTS AND POSTDOCS INVOLVED WITH THE CRG

Graduate Students:

| | |
| --- | --- |
| U. Alberta: | Tomas de Camino-Beck, Andria Dawson, Raluca Eftimie , Amy Hurford ,Chris Jerde, Martin Krkosek, Hannah McKenzie, Jung Min Lee, Peter Molnar, Tom Robbins. |
| U. British Columbia: | Alistair Blachford, Priscilla Crumrine, Brad Davis, Sandra Merchant, Jabus Tyerman. |
| U. Calgary: | Susan Bailey, Priscilla Crumrine, Kyla Flanagan,  Bill Nelson, Karilynn Sweet. |
| U. Washington: | Rebecca Dore, Jan Medlock, Tim Reluga, Damon Toth. |
| Undergraduates: | Andrew Beltaos (U. Alberta) |
| Postdocs: (not CRG Postdocs) | Erik Noonburg (U. Alberta), Alex Potapov (Research Associate, U Alberta), Shane Richards (U. Calgary), David Brian Walton (U. Wash.), Marjorie Wonham (U. Alberta). |

7. LIST OF ACTIVITIES OF THE CRG, APRIL  2003 -  OCTOBER 2006

| Date | Activity |
|---|---|
| April 30 - May 9, 2003: | 2nd annual PIMS Mathematical Biology Summer Workshop for Undergraduates, U Alberta. |
| July 5-10, 2003: | BIRS meeting: Mathematical Biology: From Molecules to Ecosystems; The legacy of Lee Segel. |
| Aug. 2003 - July 2005: | PIMS Postdoc, Dr. Frithjof Lutscher, 50% with McCauley U. Calgary and 50% with Lewis (U Alberta). |
| Sep. 2003-March 2006: | PIMS/MITACS Seminar in Mathematical Biology, U Alberta. PIMS supported speakers: Christina Cobbold (U. Glasgow), Dan Coombs (UBC), Bo Deng (U. Nebraska-Lincoln), Michael Doebeli (UBC), Bryan Grenfell (Cambridge U.), Michael Mackey (McGill U.), Bernard Roitberg (Simon Fraser U.), Birgitt Schönfisch (U. Tuebingen), Pauline van den Driessche (U. Victoria), James Watmough (U. New Brunswick),  Abba Gumel (U. Manitoba), K.P. Hadeler (U. Tuebingen), Eric Cyrtynbaum (UBC), Roger Nisbet (UC Santa Barbara), Steve Cantrell (U. Miami), Hermann Eberl (U. Guelph), Chris Cosner (U. Miami), Lou Gross (U. Tenessee). |
| Sept. 11-25, 2003: | PIMS Distinguished Chair: Dr. Bryan Grenfell, (Cambridge and Penn State), 5 lectures at U. Alberta, U. Calgary and UBC. |
| Sept. 20 - Oct. 2, 2003: | BIRS meeting: Mathematical Models for Plant Dispersal, Focused Research Group. |
| Nov. 2003 – Oct. 2004: | PIMS Postdoc, Dr. Joanna Renclawowicz, 33% with T. Hillen, 33% with M. Lewis, (both U. Alberta) and 33% with P. van den Driessche (U. Victoria). |
| Nov. 1 - Nov. 30, 2003: | Long-term visitor:  Dr. Pauline van den Driessche, (U. Victoria), 1 lecture. |
| Nov. 21, - Dec. 12, 2003: | EFF Distinguished Visitor Dr. Brian Sleeman (Leeds), 6 lecturtes a U. Alberta. |
| March 18-20, 2004: | BIRS meeting: 2-day Retreat on Mathematical Ecology and Evolution. |
| April 2004 – March 2005: | PIMS Postdoc: Dr. Mario Pineda-Krch, with Michael Doebeli, UBC. |
| May 4-14, 2004: | 3rd  annual PIMS Mathematical Biology Summer Workshop for Undergraduates, U Alberta. |
| July 18-23, 2004: | International Conference on "Differential Equations and Applications in Mathematical Biology" in Nanaimo (Vancouver Island, Canada). |
| Sept. 25 – Oct. 16, 2004: | PIMS Distinguished Chair Dr. Roger Nisbet (UC Santa Barbara). 5 lectures at UBC, U Calgary, U Alberta. |
| Nov. 27 – Dec. 2, 2004: | BIRS meeting: Biological Invasions. |
| May 2-12, 2005: | 4th annual PIMS Mathematical Biology Summer Workshop for Undergraduates, U Alberta. |
| October 1-7, 2006: | Graduate Short Course: Analysis of ecological systems under uncertainty, change and adaptation: Confronting Models with Data. Kananaskis Field Station, Alberta. |

## 8. PUBLICATIONS FROM THE CRG

The following publications are directly related to CRG activities and collaborations:

Textbook: de Vries, G., Hillen, T., Lewis, M.A., Müller, J., Schönfisch, B., A Course in Mathematical Biology: Quantitative Modeling with Mathematical and Computational Methods. SIAM, Philladelphia, 2006.

Papers:

1. Anderson, K. Nisbet, R., McCauley, E., Lewis, M.A.: Response of equilibrium states to spatial environmental heterogeneity in advective systems. (submitted to Mathematical Biosciences and Engineering, 2006).

2. Hadeler, K.P., Lewis, M.A.: Spatial dynamics of the diffusive logistic equation with sedentary component. Canadian Applied Math. Quarterly, vol 10: 473--500 (2002) (appeared in 2004).

3. Hadeler, K.P., Hillen, T., and Lutscher, F., The Langevin or Klein-Kramers Approach to Biological Modeling. M3AS (Math. Models Methods Appl. Sci.), vol 14(10), 1561-1583, 2004.

4. Hadeler, K.P. and Hillen, T. Coupled Dynamics and Quiescent States. 2006. In MATH EVERYWHERE. Deterministic and Stochastic Modelling in Biomedicine, Economics and Industry. Dedicated to the 60th birthday of Vincenzo Capasso. G. Aletti, M. Burger, A. Micheletti, D. Morale Editors, Springer, Heidelberg, 2006.

5. Hellmann J. and Pineda-Krch M. [Authors listed in alphabetical order], Constraints on adaptation under climate change: selection of genetically correlated traits. Submitted to Biological Conservation (2006).

6. Lewis, M.A., Renclawowicz, J., van den Driessche, P.: Traveling waves and spread rates for a west Nile virus model (submitted to Bull. Math. Biol. 2005).

7. Lewis, M.A., Renclawowicz, J., van den Driessche, P.: Traveling waves and spread rates for a West Nile virus model. Bull. Math. Biol. vol 68:3--23 (2006).

8. Lewis, M.A., Renclawowicz, J., van den Driessche, P., Wonham. M: A comparison of continuous and discrete time West Nile virus models. Bull. Math. Biol. vol 68:491--509 (2006).

9. Lutscher, F., Pachepsky, E., Lewis, M.A.: The effect of dispersal patterns on stream populations. SIAM J. Appl. Math., 65 (4): 1305-1327 reprinted in SIAM Rev. vol 47:749--772 (2005) as SIGEST selection.

10. Lutscher, F., Lewis, M.A.: Spatially-explicit matrix models: A mathematical analysis of stage-structured integrodifference equations. J. Math. Biol. vol 48: 293--324 (2004).

11. Lutscher, F., Lewis, M.A., McCauley, E.: Effects of heterogeneity on spread and persistence in rivers. Bull. Math. Biol. DOI: 10.1007/s11538-006-9100-1 (2006).

12. Lutscher, F., McCauley, E., Lewis, M.A.: Spatial patterns and coexistence mechanisms in rivers. (in revision at Theor. Pop. Biol., 2006).

13. Lutscher, F., Pachepsky, E., Lewis, M.A.: The effect of dispersal patterns on stream populations. SIAM J. Appl. Math. vol 65:1305--1327 (2005).

14. Pachepsky, L., Lutscher, F., Nisbet, R., Lewis, M.A.: Persistence, spread, and the drift paradox. Theor. Pop. Biol. Vol 67:61--73 (2005).

15. Pineda-Krch M., Blok H., Dieckmann U. and Doebeli M. A tale of two cycles --- Distinguishing between true limit cycles and quasi-cycles in finite predator-prey populations. Oikos, (2006) In press.

16. Pineda-Krch, M., Svanback, R. and Doebeli, M. Fluctuating population dynamics promotes the evolution of phenotypic plasticity. (2006), In preparation.

17. Renclawowicz, J. and Hillen, T., Analysis of an Attraction-Repulsion Chemotaxis Model. 2005, (in revision).

18. Svanback, R., Pineda-Krch, M. and Doebeli, M. Adaptive evolution and then what? (2006), In preparation.

19. Wang, Z. and Hillen, T. Shock Formation in a Chemotaxis Model, 2005, submitted to J. Differential Equations.

20. Wonham, M.W, Renclawowicz, J., van den Driessche, P., Lewis, M.A.: Dynamical mathematical models of arboviral encephlitis ecology: perspectives and future directions (in preparation).

21. Wonham, M.J., Lewis, M.A., Renclawowicz, J., van den Driessche, P.: Dynamical mathematical models of West Nile-like diseases: Model structure and disease control implications. Ecology Letters, vol 9 (2006).