

**Describing and understanding host-pathogen community interaction at the
wildlife/domestic interface**

By

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Describing and understanding host-pathogen community interaction at the
wildlife/domestic interface

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Abstract

In this thesis, I investigated the relationship between host and pathogen in multi-host and multi-pathogen systems at the interface between wildlife and domestic species. The term “epidemiological interaction” was central to my thesis, and was defined as “any ecological interaction between two host populations resulting in the transmission of one or more pathogen”. Epidemiological interactions are related to the processes of transmission between hosts and I investigated how these epidemiological interactions between different host populations could be investigated in a given ecosystem. I developed two research frameworks to estimate these epidemiological interactions: 1) an *a priori* approach based on the host data and assuming that the mobility of hosts and the resulting contacts between host populations would be crucial factors influencing the epidemiological interactions; 2) an *a posteriori* approach based on the pathogen data, assuming that epidemiological pathways previously used by some pathogen species can be used in the future by other pathogens. The animal-pathogen model used to test the first approach was the bird-avian influenza viruses’ model. Longitudinal counting and sampling protocols of domestic and wild birds over two years were used to analyse community composition and abundance of hosts to compare with the prevalence of avian influenza viruses. I could, for the first time, show a persistence of low pathogenic avian influenza strains in an African ecosystem, and investigate the relationships with both the potential maintenance hosts (Afro-tropical ducks and resident species) and hosts that introduced the virus into the system from Europe or Asia (palaearctic migrants). With the estimation of epidemiological interaction using host community data, I estimated the contact rate between wild and domestic avian compartments (intensive poultry, backyard and farmed ostrich compartments) and assigned a risk to this interaction based on dynamic and non-

dynamic factors for each bird species. This approach highlights the species or seasons at risk for the domestic compartments (or for the wild bird compartments depending on the perspective) in order to orientate surveillance or control options. This type of data and framework can also be used in mechanistic modelling to predict the spread of a pathogen after its introduction in one compartment. I tested the host approach in a broader dataset at the Southern African region level with similar counting and sampling database in multiple study sites, showing that the variability of host communities across the region could explain the variability of pathogen detection (however, finding a causal relationship was impossible). Finally, I theoretically developed the pathogen approach by combining tools used in parasite community ecology, molecular epidemiology and social network analysis and gave a theoretical example using a rodent and human macro and microparasite dataset.

This thesis has explored the field of transmission ecology and offered ways to quantify the processes of transmission between host populations. Theoretically, I have developed a fundamental reflexion around epidemiological interactions and formulated hypotheses on their potential for being independent of the parasite species. Practically, I have developed tools to provide information for decision-making in order to improve efficiency of surveillance and control programmes at the wildlife/domestic interface particularly adapted to detect emerging infectious disease spill-over process.

I, Alexandre Caron, declare that the thesis/dissertation, which I hereby submit for the degree of Doctor of Philosophy at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

SIGNATURE:

DATE: 15 January 2011

Summary

Describing and understanding host-pathogen community interaction at the
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By

Alexandre Caron

Doctor of Philosophy in

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University of Pretoria

I have defined the concept of epidemiological interaction (EI) between two host populations (**Chapter One** is a theoretical introduction). Then I have presented two approaches to estimate these EIs. The first one, described in **Chapter Two**, assumes that the movements of hosts and the contacts induced by this mobility will contribute to estimating EIs. The second one (**Chapter Seven**) assumes that there is a limited quantity of potential transmission pathways between two host populations and that past occurrence of disease transmission can estimate future occurrence of pathogen spill-over or disease emergence.

In this thesis, I have developed mostly the first approach. Using the model of wild and domestic avian communities in a Zimbabwean wetland, I have gathered longitudinal ecological and epidemiological data to provide information about Avian Influenza viruses (AIV) in a multi-host system. In **Chapter Three**, I have explored how a host community approach can help defining a risk season, and risk species for the epidemiological cycle (reservoir, spreader, maintenance host) and at the wildlife/domestic interface. This has been used to identify potential bridge species able to spread the pathogen from a source host population to a target host population. In **Chapter Four**, I suggest for the first time a yearly persistence of AIV in an African ecosystem based on multi-species data and by exploring potential mechanisms for this persistence. In **Chapter Five**, I show how ecological and epidemiological data can be integrated in a risk analysis to estimate the risk of pathogen spread through wild birds and present a framework for animal health services to increase the efficiency of their surveillance at the wildlife/domestic interface. **Chapter Six** explores the complexity of predicting AIV circulation in wild bird communities at the southern African level, based on a regional dataset and presenting an epidemiological functional group approach (borrowed from the functional group concept in community ecology). Articles included as appendices show how this work is integrated in a broader framework of research on the ecology of AIV in waterbirds (**Appendix One, Two, Four & Five**).

In parallel, the same approach was used in wild/domestic ungulate community in the South-East Lowveld of Zimbabwe, exploring transmission pathways for bovine tuberculosis and other important diseases (**Appendix Three** & on-going manuscripts). The juxtaposition of these models highlights the process-centred approach that I have focused on instead of a host- or pathogen-centred approach: I am (in collaboration with my colleagues) exploring and testing the same hypotheses in the two models.

In **Chapter Seven** (and **Appendix Six**), I present the pathogen approach that I have developed, presenting the conceptual and operational framework to identify the most likely transmission pathways at the community level using social network analysis. I use an example on rodent community and their parasite community in South East Asia (Box in **Chapter Seven**).

Finally, in **Chapter 8**, I synthesise the finding of this thesis, try to provide a research framework for future research and discuss future breakthrough in technology which will provide major advances in the ecology of disease transmission.



Note on the text

Each chapter is set out in the style of the journal to which it has or will be submitted. Consequently there is some repetition and stylistic differences in each of the chapters. In addition, other authors are included in the paper reference. However, for each chapter, my input was the greatest. I planned research, undertook the field work, analysed the data and wrote the manuscripts. I was helped by my co-authors. Elissa Cameron, Michel de Garine-Wichatitsky, David Cumming and Serge Morand were my supervisors.

Acknowledgements

Starting from the beginning, I would like to thank my parents and my sister for giving me the opportunity to grow and then study in a perfect family environment. My parents gave me the education and the will to have goals to achieve and dreams to fulfill. This thesis is the completion of both. A tous les trois, mille mercis pour votre aide, soutien et amour.

If I engaged in a Phd thesis at some point of my career, it is because someone advised me to do so and felt that I could become a researcher. I did not agree at that time but he was right. I would like therefore to thank François Monicat, former head of the research unit I belong to who gave me that piece of advice at the right time. In addition, he put me in a professional position in Zimbabwe, where I could build a proper framework for this thesis and implement it with time and means.

On the (long) way to become a researcher (and I still have some way to go), I met Michel de Garine-Wichatitsky, a “real” researcher, with the right spirit and skills to train me. We have shared the same office for more than four years now and this type of relationship can only evolved in two ways: we took the right one. Fortunately, he was patient and diplomat enough to accept my numerous questions about protocols, statistical issues and relevance of my thoughts and writing. He had a huge impact on this thesis and I hope we will be able to share this professional experience for many more years. I am honored to be able to benefit from his experience and friendship.

This PhD thesis cannot be a one-person achievement, even if I am responsible for all its imperfections. It represents more than four years of collaboration with researchers and non-researchers. First of all, I would like to thank my supervisor, Elissa Cameron who accepted me as a PhD student based on trust and a few ideas on a piece of paper. Then, Elissa

has always been supportive of my project, ready to help me on manuscripts and to reformulate clearly my thoughts. I only regret that I could not show her my study sites in Zimbabwe due to time and agenda constraints. My co-supervisors, Michel de Garine-Wichatitsky, Serge Morand and David Cumming helped me a lot to give this thesis a proper framework and to bring a necessary eagle-view to my different works. They have spent much of their precious time for me and I will always be thankful for that. This thesis is also a tremendous collaborative study involving researchers from Europe, Africa and Asia. I would like to highlight the good spirit that prevails in the AGIRs research unit of Cirad in which I was hosted all these years. I met incredible researchers and friends and only hope to justify my place in their team in the future. I had very good collaborations with various institutes and research unit. First in Zimbabwe, I was kindly hosted by the research platform RP-PCP (Production and Conservation in Partnership), a collaborative experience between University of Zimbabwe, the National University of Sciences and Technology (NUST), Cirad and CNRS. Then through various projects, I had the chance to work with the Mammal Research Institute of course, but also the ARC-OVI (Agricultural Research Council - Onderstepoort Veterinary Institute) research laboratory in Pretoria, and the Fitz-Patrick Institute in Cape Town.

A part from methodology and theoretical science, field activities were an important part of this thesis. Through the year, I was helped by many skilled and motivated individuals that I cannot all cite. The Cirad team in the Zimbabwean office provided me with a good and supportive environment to develop my research. I will also thank the Veterinary Services of Zimbabwe and the Park and Wildlife Management Authority of Zimbabwe which provided me with access to their fields, supportive staff and various technical and administrative supports. Despite a very difficult socio-economic context in Zimbabwe at the beginning of this thesis, they always answered present to my requests. Finally, I was closely helped by a

research assistant, Ngoni Chiweshe, a skilled ornithologist who became an efficient bird sampler and a good database handler!

Research can only be implemented if donors support ideas and projects. The French Ministry of Foreign Affairs (MAEE) has funded the Mesures d’Urgence and GRIPAVI projects from 2007 to end of 2011. The French Embassy in Zimbabwe has also always been supportive of Cirad activities in the country and helped many Zimbabwean students to achieve graduate and post-graduate degrees by completing projects related to this thesis. FAO (Food and Agriculture Organisation), the European Union office in Zimbabwe (PARSEL project) were also supportive of this project.

Finally this thesis, despite all the collaboration cited, is a single individual responsibility. If I can pretend to be the one who completed this work, it can only be due to my personal well-being. Friends in France, Zimbabwe, South Africa and elsewhere are crucial to keep a personality alive. But I will not be myself without Carole. She left her life in France to follow me in an unknown continent, to build a complete new life in a new environment and at the same time, supporting my absences and my doubts. She managed to create a new family environment around us, first together, and then with our wonderful daughters, Eva and Noémie who landed in our life during this thesis. This was the environment I needed to complete this thesis.

These five years in Zimbabwe would mean a lot in my life, forever.

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