Funded by the National Center for Ecological Analysis & Synthesis
September 2003

(Application for postdoctoral fellowship)

Title: Risk Analysis for Alien Species and Emerging Infectious Diseases
Short Title: Risk Analysis in Ecology

Name & Contact Information:
John M. Drake
Department of Biological Sciences
University of Notre Dame
Notre Dame, IN 46556
email: drake.4@nd.edu

Summary (for public distribution on website):

Undesirable alien species and emerging infectious diseases (of both wildlife and humans) are urgent environmental concerns. Considerable effort has therefore been invested in understanding the ecology and evolution of invasive species and of infectious diseases. Despite exhibiting similar dynamics that are modeled with the same techniques, these phenomena are commonly studied by separate research communities for the purposes of risk analysis, management, and control. This project will develop techniques for risk analysis of intentional and unintentional introductions of non-indigenous species and will investigate areas of cross-fertilization with epidemiological theory. The products of this study will be tools for decision-making in the presence of uncertainty and specific recommendations for six case studies.

Problem Statement:
The proposed research asks two questions:

(1) What are the relationships between propagule pressure (the size of an introduced population or number of infectious individuals) and the chance of invasion and disease outbreak?

(2) What interventions are available to manage propagule pressure before invasion or disease outbreak occurs and to control invasions and epidemics already in progress?

Two areas of potential cross-fertilization between invasion ecology and epidemiology will help to answer these questions:

(1) Stochastic dynamical models may be used to relate the chance of invasion/epidemic to propagule pressure; and

(2) Rational decision theory, by considering both stochastic dynamics and epistemic uncertainty, can provide quantitative guidance toward balancing social risks and benefits.

Rationale for NCEAS Support:
The research proposed here will include considerable mathematical modeling and computer simulation, which are research strategies supported at NCEAS. Moreover, as a leading international center for theoretical ecology NCEAS is the ideal intellectual setting for conducting the proposed project, which will not require original data collection. Additionally, the work proposed here would complement a potential working group to compare risk analyses for non-indigenous species, genetically modified organisms, and biocontrol agents (to be proposed by L. Wolfenbarger & D.M. Lodge in January 2004) as well as several active NCEAS working groups (Leaders: Altizer & Nunn, Harvell, Real & Dobson, Wilson & Real). I would be eager to participate in one or more of these working groups should they be open to new participants. Finally, by bringing together ideas about the dynamics of invasive alien species and emerging infectious diseases, the proposed research shares the goals of NCEAS' mission to foster collaborations that synthesize information in the search for general ecological principles and patterns.

Proposed Activities (including timetable):

In my previous research I developed stochastic population growth models to inform risk analyses for introductions of non-indigenous species in ballast water. A focus of my research was forecasting invasion dynamics with considerable biological realism. Features of these models included variable environmental conditions, Allee effects, seasonality, mate limitation, passive transport, and irregular spatial boundaries. I also developed statistical models to predict the identity of future invasive mollusks and an allometric model to derive specific recommendations for ballast water policy. In the proposed research, I will continue development of these techniques and will extend their scope to include emerging and re-emerging infectious diseases, as defined by the CDC (CDC 2003).

The overall approach will be to develop stochastic dynamical models that describe and predict the chance of invasion/epidemic. These models will be validated with existing data. Model outcomes will be put into a decision-theoretic framework for managing risk in which probabilistic reasoning is used to evaluate possible management options in situations of uncertain predictions. In my view, uncertain predictions stem from two causes, random processes and epistemic uncertainty, both of which must be considered to devise meaningful calculations of risk and which are not simply multiplicative (Ferson & Ginzburg 1996). This view is similar to that of the USEPA (1998) for ecotoxicology risk assessment. In specific cases the analytical techniques used to evaluate the decision set are dictated by the available data and model complexity. Among these are standard inferential statistics (*e.g.* GLM, logistic regression), analytical models of stochastic processes (Fokker-Planck equation), Markov Chain Monte Carlo (MCMC), neural networks, non-parametric analyses including bootstrap and cross-validation (for measurement uncertainty and model validation), and linear and quadratic programming (for optimization).

Under this rubric, I have specified three sub-projects that attend to urgent environmental concerns and are feasibly addressed with existing data. Below, I provide a brief description of each numbered sub-project. Following is a timeline for completion of these projects (Table 1). The proposed timeline has been constructed with three goals in mind: (1) continuity between sub-projects; (2) project feasibility and focus; and (3) even distribution of theory development and data analysis.

1. Decision theory for managing risk of invasion and epidemic.

Decision theory is a mathematical and computational framework for consistent decision-making about the control of stochastic processes (such as the introduction of non-indigenous species or infectious individuals) in the presence of uncertainty (Joyce 1999, Jeffrey 1983). Theoretical challenges result from the need to propagate natural variability and uncertainty differently in forecasts (Ginzburg & Ferson 1996). In this sub-project I will develop a decision-theoretic framework for managing the propagule pressure of alien species and extensions to emerging infectious diseases for the specific cases detailed below.

Case I: Introductions of Alien Species

Case studies dealing with the introduction of a single species will focus on strategies for managing invasions of alien species already underway. First, I will evaluate approaches to controlling the transfer of Spiny water flea (*Bythotrephes longimanus*) among inland lakes in the upper Midwestern USA and Canada. This study will comprise the extension of a local model I developed (Drake *in press*) to the landscape scale. Data for this sub-project are owned by me or are available from existing collaborations. Second, I will use stochastic demographic models to evaluate alternatives for slowing or halting the spread of annual plants on the perimeter of Kruger National Park, South Africa. Data for this sub-project are available through a cooperative agreement with CSIR Environmentek. (See attached letter of support.)

If time permits, a multi-species case study will examine strategies for reducing the risk of invasion from ballast water in the Great Lakes. In my dissertation research I collaborated on research to determine invasion risk in the Great Lakes from ballast water and sediments. It is our opinion that this study (now in its final stages) would be most useful to managers if published as a monograph. My collaborator on this project, David Lodge, will be seeking a sabbatical fellowship at NCEAS during this time, which, if granted, will expedite the process by facilitating our ability to write cooperatively. Data for this project are owned by me and/or David Lodge.

Case Study II: Emerging and Re-emerging Infectious Disease.

Extensions of the above techniques will address the disease ecology of human beings, livestock, and wildlife. Specifically, I will evaluate potential interventions for emerging infectious diseases in the stages immediately following discovery. The primary candidate for case study is bovine tuberculosis (*Mycobacterium bovis*) in Michigan (USA) and Kruger National Park (South Africa). Potential interventions to be explored include proactive actions (*e.g.* isolating susceptible populations, quarantine) and damage mitigation (*e.g.* culling). Data for the USA are available from the US Department of Agriculture (USDA) Animal and Plant Health Inspection Services (APHIS) surveillance programs. Additionally, Dr. Wayne Getz (U.C. Berkeley) and Dr. Harry Biggs (Kruger National Park, South Africa) responded favorably to initial inquiries about collaborating on bovine tuberculosis in Kruger National Park. Alternative models are transmissible spongiform encephalopathies (TSEs) including West Nile Virus and Chronic Wasting Disease. Data for these diseases are available from the National Center for Infectious

Diseases Division of Vector-Borne Infectious Diseases West Nile Virus surveillance program and the USDA.

While models employed in Case Studies I and II will differ slightly, reflecting the different modes of reproduction and dispersal for free-living versus pathogenic species, this sub-project will underscore the biological continuity between them and the similarity among techniques for risk analysis.

2. Pair formation, Allee effects, and the initial dynamics of infectious diseases.

One of my present research interests is the role of mate limitation, which causes Allee effects in population dynamics (Courchamp *et al*. 1999; Drake *in press*). This feature of population biology has an analog in theoretical epidemiology: the problem of pair-formation (Kretzschmar & Dietz 1998). In this sub-project I will extend standard models of stochastic population dynamics (Matis & Kiffe 2000, Renshaw 1991) to include nonlinearities caused by two interacting sexes and I will develop and apply these techniques to pair formation in epidemic models.

Some progress has been made toward this problem in the theoretical population biology literature (*e.g.* Ashih 2001), though applications are rare. Through a modeling study, I will seek to answer the question: How does the chance of invasion or epidemic change with propagule pressure under different, realistic conditions for pair-formation including heterogeneous encounter rates? How poorly do models perform when pair-formation is ignored? Model development incorporating these complicating factors is currently underway. While at NCEAS, I will complete model development and demonstrate why including these characteristics is necessary through case studies. Potential model species are (i) Eurasian ruffe (*Gymnocephalus cernuus*), (ii) Brown trout (*Salmo trutta*), (iii) Rusty crayfish (*Orconectes rusticus*), and (iv) Spiny water flea. Data for (i), (iii), and (iv) are available through existing collaborations. Data for (ii) are obtainable from (Elliot 1994). Potential model species and data for epidemic models are as in Case Study II, above.

3. Infectious disease dynamics in a metapopulation: stochastic network analysis.

If time permits I will investigate potential applications of stochastic network analysis to risk analysis for invasions of alien species and emerging infectious diseases. This sub-project is the most speculative aspect of the proposed research, but offers considerable promise for developing new methodology. At present, large-scale risk analysis for both alien species and emerging infectious diseases is impeded by the computational complexity of models for interconnected, spatially distributed stochastic processes. Although local stochastic processes can be modeled independently, doing so makes the often-erroneous assumption that populations are virtually isolated. (Examples of local stochastic processes that should be integrated at a landscape scale are initial establishment of beachhead populations and initial infection dynamics.) In this sub-project I will attempt to use stochastic optimization techniques for random networks (*e.g.*

Serfozo 1999, Kelly *et al*. 1996) to model invasions/epidemics in metapopulations. This will be a theoretical study.

Anticipated Results & Beneficiaries:

In this study I will develop techniques for risk analysis and demonstrate their usefulness with case studies. Beneficiaries of sub-project (1) will include: legislative bodies and their advisors such as the National Invasive Species Advisory Committee (pending legislation includes the National Aquatic Invasive Species Act of 2003 (S.525, HR.1080) and International Convention On the Control and Management of Ships' Ballast Water and Sediments); wildlife managers at Kruger National Park; the USEPA, Great Lakes Fisheries Commission, and Illinois-Indiana Sea Grant, which funded earlier studies leading to this proposal; and other interested ballast water stakeholder groups include the shipping industry (which is interested in reducing liability) and the U.S. Coast Guard (which is responsible for enforcing legislation). Additional beneficiaries of this sub-project will include biologists interested in methodology for detailed location- and species-specific invasion risk analyses. Beneficiaries of sub-projects (2) and (3) will be risk analysts and public health decision-makers for emerging infectious diseases. Additionally, because the approach I take contributes to theory in population biology while management applications are developed, I hope that a meaningful contribution will also be made to basic scientific research in ecology, demography, and epidemiology.

CV: see below

Year	Month	1. Decision Theory for Alien Species & EID	2. Pair Formation & Allee Effects	3. Metapopulations
2004	Jun	Case Study I: Alien Species		
	Jul	Decision Theory		
	Aug			
	Sept	**Spiny Water Flea**		
	Oct			
	Nov	Invasive Plants		
	Dec			
2005	Jan			
	Feb		Simulation Models	
	Mar	Ballast Water		
	Apr			
	May	Case Study II: Emerging Infectious Diseases	Alien Species: **Ruffe, Brown Trout, Rusty**	
	Jun	Decision Theory	**Crayfish, Spiny Water Flea**	
	Jul			
	Aug			
	Sept		Pathogens: **West Nile Virus**	
	Oct		**Chronic Wasting Disease**	
	Nov	**Bovine Tuberculosis**		
2006	Dec			
	Jan			Stochastic Network
	Feb			Analysis
	Mar			
	Apr			

Table 1. Timeline for completion of sub-projects. Shading indicates case studies. No shading indicates theory development. Bold type indicates potential species for case studies.

References:

Ashih, A. 2001.Spatial and stochastic models for population growth with sexual and asexual reproduction. Ph.D. thesis. Duke University.

CDC (Centers for Disease Control). 2003. *Emerging Infectious Diseases*. http://www.cdc.gov/ncidod/EID/about/background.htm

Drake, J.M. (in press). Allee effects and the risk of biological invasion. *Risk Analysis*.

Elliot, J.M. 1994. *Quantitative Ecology and the Brown Trout.* Oxford University Press.

Ferson, S. and L.R. Ginzburg. 1996. Different methods are needed to propagate ignorance and variability. *Reliability Engineering and Systems Safety* 54:133-144.

Jeffrey, R.C. 1990. *The Logic of Decision*, 2nd ed. Chicago University Press.

Joyce, J. 1999. *The Foundations of Causal Decision Theory*. Cambridge University Press.

Kelly, F.P., S. Zachary & I. Ziedins, eds. 1996. *Stochastic Networks: Theory and Applications*. Royal Statistical Society Lecture Note Series No. 4. Oxford University Press. 384 pp.

Kretzschmar, M. & K. Dietz. 1998. The effect of pair formation and variable infectivity on the spread of an infection without recovery. *Mathematical Biosciences* 148: 83-113.

Matis, J.H. & T.R. Kiffe. 2000. *Stochastic Population Models: A Compartmental Perspective*. Lecture Notes in Statistics 145. Springer: New York.

Renshaw, E. 1991. *Modelling Biological Populations in Space and Time*. Cambridge University Press.

Serfozo, R. 1999. *Introduction to Stochastic Networks*. Springer: New York.

USEPA 1998. *Guidelines for Ecological Risk Assessment.* USEPA EPA/630/R095/002F. 01 Apr 1998. U.S. Environmental Protection Agency, Risk Assessment Forum, Washington, DC, 175 pp.