Michael H. Cortez

Assistant Professor
Department of Mathematics and Statistics, Utah State University

---

Contact Information

Department of Mathematics and Statistics
Utah State University
3900 Old Main Hill
Logan, UT 84322-3900

E-mail: michael.cortez@usu.edu
Telephone: (435) 797-9174
Webpage: http://www.math.usu.edu/cortez/

Education

Ph.D. 2011 Cornell University: Applied Mathematics
Advisor: Stephen P. Ellner (Ecology & Evolutionary Biology)
Committee Members: John Guckenheimer (Mathematics)
Nelson G. Hairston, Jr. (Ecology & Evolutionary Biology)
Minors: Ecology & Evolutionary Biology and Mathematics

M.S. 2008 Cornell University: Applied Mathematics
Advisor: Stephen P. Ellner (Ecology & Evolutionary Biology)

B.S. 2005 Hope College: Chemistry and Mathematics
Advisor: William F. Polik (Chemistry)

Employment History

2014- Assistant Professor, Department of Mathematics and Statistics, Utah State University

2014- Faculty Associate, Ecology Center, Utah State University

2012-2014 NSF Mathematical Sciences Postdoctoral Research Fellow, School of Biology, Georgia Institute of Technology
Mentor: Joshua Weitz

2010-2012 Postdoctoral Researcher, School of Biology, Georgia Institute of Technology
Affiliate of the School of Mathematics
Mentor: Joshua Weitz

Awards and Honors

2016-2020 Ecological Society of America Early Career Fellow

2016 Utah State University Washington, DC Faculty Fellow

2012-2014 NSF Mathematical Sciences Postdoctoral Research Fellow

2011 Prize for an outstanding paper in ecological theory in 2011. Theoretical Ecology Section of the Ecological Society of America. Awarded for 2011 *Ecology Letters* paper

2009 Provost's Diversity Graduate Student Fellowship

2005-2008 Alfred P. Sloan Foundation Graduate Fellowship

2005 Elected to Sigma Xi

2004 Elected to Phi Beta Kappa

2001 Eagle Scout Award

Grants & Funding

Current Funding

2018 National Science Foundation, Division of Environmental Biology. "Collaborative Research: Development and empirical tests of a mechanistic multi-host, multi-pathogen theory."
PIs: Michael H. Cortez & Meghan A. Duffy (University of Michigan).
(Total award: $735,288; Cortez: $203,399)

Previous Funding

2012-2014 National Science Foundation Postdoctoral Research Fellowship in Mathematical Sciences. "Understanding eco-coevolutionary dynamics through the use and development of fast-slow dynamical systems theory." ($150,00)

PUBLICATIONS (*=GRADUATE STUDENT)

1. **M.H. Cortez**. Genetic variation and the drivers of eco-coevolutionary predator-prey cycles. *Ecological Monographs* 88: 353-371.
2. S. Patel*, **M.H. Cortez**, and S.J. Schreiber. Partitioning the effects of ecology, evolution, and eco-evolutionary feedbacks on community stability. *American Naturalist* 191: 381-394.
3. **M.H. Cortez** and S. Patel*. 2017. The effects of predator evolution and genetic variation on predator-prey population-level dynamics. *Bulletin of Mathematical Biology* 79: 1510-1538.
4. Z. Pu*, **M.H. Cortez**, and L. Jiang. 2017. Predator-prey coevolution drives productivity-richness relationships in planktonic systems. *American Naturalist* 189:28-43.
5. **M.H. Cortez**. 2016. How the magnitude of prey genetic variation alters predator-prey eco-evolutionary dynamics. *American Naturalist* 188: 329-341.
6. **M.H. Cortez**. 2016. Hydra effects in discrete-time models of stable communities. *Journal of Theoretical Biology* 411: 59-67.
7. **M.H. Cortez** and P.A. Abrams. 2016. Hydra effects in stable communities and their implications for system dynamics. *Ecology*, 97: 1135-1145.
8. C. L. Searle, **M.H. Cortez**, *8 other authors*, and M. A. Duffy. 2016. Population density, not host competence, drives patterns of disease in an invaded community. *American Naturalist* 188: 554-566.
9. **M.H. Cortez**. 2015. Coevolution-driven predator-prey cycles: Predicting the characteristics of eco-coevolutionary cycles using fast-slow dynamical systems theory. *Theoretical Ecology* 8: 369-382.
   – Recommended by Faculty of 1000 (F1000)
10. P. A. Abrams and **M.H. Cortez**.† 2015. The many potential indirect interactions between predators that share competing prey. *Ecological Monographs* 85: 625-641.
   †Authors contributed equally
11. P.A. Abrams and **M.H. Cortez**. 2015. Is competition needed for ecological character displacement? Does displacement decrease competition? *Evolution* 69: 3039-3053.
12. L. F. Jover*, C. O. G. Flores*, **M.H. Cortez**, and J. S. Weitz. 2015. Multiple regimes of robust patterns between network structure and biodiversity. *Scientific Reports* 5: 17856.
13. **M.H. Cortez** and J.S. Weitz. 2014. Coevolution can reverse predator-prey cycles. *Proceedings of the National Academy of Sciences*, 111: 7486-7491.
14. B.P. Taylor*, **M.H. Cortez**, and J.S. Weitz. 2014. The virus of my virus is my friend: ecological effects of virophage with alternative modes of coinfection. *Journal of Theoretical Biology* 354: 124-136.
15. **M.H. Cortez**. 2013. When does pathogen evolution maximize R_0 in well-mixed host-pathogen systems. *Journal of Mathematical Biology* 67: 1533-1585.
   – Recommended by Faculty of 1000 (F1000)
16. **M.H. Cortez** and J.S. Weitz. 2013. Distinguishing between indirect and direct modes of transmission using epidemiological time series. *American Naturalist* 181: E43-54.
17. L.F. Jover*, **M.H. Cortez**, and J.S. Weitz. 2013. Mechanisms of multi-strain coexistence in host–phage systems with nested infection networks. *Journal of Theoretical Biology* 332: 65-77.
18. **M.H. Cortez**. 2011. Comparing the qualitatively different effects rapidly evolving and rapidly induced defences have on predator-prey interactions. *Ecology Letters* 14: 202-209.

19. **M.H. Cortez** and S.P. Ellner. 2010. Understanding the effects of rapid evolution on predator-prey interactions using the theory of fast-slow dynamical systems. *American Naturalist* 176: E109-E127.
20. T.L. Bultman, T.J. Sullivan, **M.H. Cortez** and T.J. Pennings. 2009. Extensions to and modulation of defensive mutualism in grass endophytes *in* Defensive mutualism in microbial symbiosis, eds. J. F. White and M. S. Torres. CRC Press, p. 301 - 317.
21. **M.H. Cortez**, et al. 2007. Factors contributing to the accuracy of harmonic force field calculations in water. *Journal of Chemical Theory and Computation* 3: 1267-1274.
22. B. Alleman, **M.H. Cortez**, et al. 2003. Take me out to/of the ball game. *Rose-Hulman Undergraduate Math Journal* 4: 2.

Submitted Manuscripts (*=Graduate Student)

1. **M.H. Cortez**, S. Patel, and S. Schreiber. Eco-evolutionary cycles in empirical systems are driven by destabilizing evolutionary and prey eco-evolutionary feedbacks. Submitted.
2. **M.H. Cortez** and M. Yamamichi. The indirect effects of species adaptation: indirect evolutionary rescue and hydra effects. Submitted.
3. J.S. Weitz, G. Li, H. Gulbudak, **M.H. Cortez**, and R.J. Whitaker. Viral fitness across a continuum from lysis to latency. Submitted
4. P.A. Clay*, **M.H. Cortez**, M.A. Duffy and V.H.W. Rudolf. Priority effects within co-infected hosts alter prevalence relationships between parasites at the host population scale. Submitted

Mentoring Experience

2016- PhD student advisor - Guen Grosklos
Dept of Math and Stats, Utah State University
1 manuscript in prep

2016- Graduate committee member for 4 graduate students: Lacy Smith (Natural Resources PhD; 2017-present), Alexandro Rego (Biology MS; 2017-present), Ian McGahan (Applied Math PhD; 2016-present), Eden Furtak-Cole (Applied Math PhD; 2015-2017).

2011-2014 PhD student research mentor - Luis F. Jover
School of Physics, Georgia Institute of Technology, co-mentored with Joshua S. Weitz
2 resulting publications: Jover et al., 2013 & 2015.

2012-2014 PhD student research mentor - Bradford P. Taylor
School of Physics, Georgia Institute of Technology, co-mentored with Joshua S. Weitz
1 resulting publication: Taylor et al., 2014.

2012 PhD student research mentor - Cesar Garcia Flores
School of Physics, Georgia Institute of Technology, co-mentored with Joshua S. Weitz

2012-2013 Undergraduate student research mentor - Yido Jang
Biomedical Engineering, Georgia Institute of Technology

2008 REU undergraduate student research mentor
Department of Mathematics, co-mentored with Tim J. Penning

Teaching Experience

Linear Algebra (Math 2270), Utah State University, F2017, F2016, S2016, & F2015
50-60 undergraduate students, average teaching effectiveness: 4.6/5

Methods in Applied Mathematics (Math 5410), Utah State University, F2017, F2016
20 grad/undergrad students, average teaching effectiveness: 4.5/5

Modeling Predator-Prey Interactions (Bio 4230 & Math 6910), Utah State University, S2016. 12 grad/undergrad students, average teaching effectiveness: 4.5/5

Analysis of biological models using fast-slow dynamical systems (Math 6910), Utah State University, S2016. 4 graduate students, average teaching effectiveness: 5/5

Calculus 2 (Math 1220), Utah State University, S2015.
66 undergraduate students, average teaching effectiveness: 4.1/5

Theoretical Ecology (Bio 4422/6422), Georgie Institute of Technology, S2012. Co-taught with Joshua S. Weitz. 13 grad/undergrad students, average teaching effectiveness: 4.4/5

Guest lecturer for Viral Ecology (School of Biology, Georgia Institute of Technology) and Ecology (Department of Biology & Physics, Kennesaw State University)

Organized Sessions

1. Society of Mathematical Biology Annual Conference, Tempe, Arizona (6/2013). *Modeling the interactions between ecological and evolutionary processes: Fast, slow, and everything in between.*

Invited Talks

2018

1. ESA Annual Conference, New Orleans, LA

2017

1. SIAM Conference on applications of dynamical systems, Snowbird, UT
2. Department of Ecology and Evolutionary Biology, UCLA, Los Angeles, CA
3. Department of Ecology, Evolution, and Natural Resources, Rutgers University, New Brunswick, NJ

2016

1. Department of Ecology and Evolutionary Biology, University of Toronto, Toronto, Ontario, Canada
2. Department of Ecology and Evolutionary Biology, University of Michigan, Ann Arbor, MI
3. Department of Biology, Indiana University, Bloomington, IN
4. Department of Mathematics, University of Utah, Salt Lake City, UT

2015

1. Department of Ecology and Evolutionary Biology, University of Michigan, Ann Arbor, MI
2. ESA Annual Conference, Baltimore, MD
3. School of Mathematical and Statistical Sciences, Arizona State University, Tempe, AZ

2014

1. Modeling Infectious Diseases Group, Center for Disease Control, Atlanta, GA
2. Department of Mathematics and Statistics, Utah State University, Logan, Utah
3. Department of Biology, Stanford University, Stanford, California
4. Biology Department, University of Massachusetts Boston, Boston, Massachusetts
5. Department of Applied and Computational Mathematics and Statistics, University of Notre Dame, South Bend, Indiana
6. Department of Mathematics, University of Idaho, Moscow, Idaho
7. Department of Ecology and Evolutionary Biology, University of Toronto, Toronto, Ontario, Canada.
8. Department of Biological Science, Florida State University, Tallahassee, Florida

2013

1. Department of Biology, University of Kentucky, Lexington, Kentucky
2. Department of Ecology and Evolutionary Biology, University of Toronto, Toronto, Ontario, Canada
3. Department of Mathematics and Statistics, Queen's University, Kingston, Ontario, Canada
4. MBI Workshop 2: Rapid Evolution and Sustainability, Mathematical Biosciences Institute, Ohio State University, Columbus, Ohio
5. SACNAS Annual Meeting, San Antonio, Texas

6. Evo.Tech Seminar Series, Georgia Institute of Technology
7. SIAM Annual Conference, San Diego, California
8. Society of Mathematical Biology Annual Conference, Tempe, Arizona
9. 11th Annual EEID Conference, State College, Pennsylvania

2010 and earlier

1. School of Mathematics, Georgia Institute of Technology, Atlanta, Georgia
2. SIAM 2009 Annual Conference, Denver, Colorado

Contributed Talks

1. ESA 2017 Annual Conference, Portland, OR
2. SMB 2017 Annual Conference, Salt Lake City, UT
3. SMB 2015 Annual Conference, Atlanta, GA
4. ESA 2013 Annual Conference, Minneapolis, MN
5. ESA 2012 Annual Conference, Portland, OR
6. SMB 2012 Annual Conference, Knoxville, Tennessee
7. ESA 2011 Annual Conference, Austin, TX
8. MBI 2010 Workshop for Young Researchers in Mathematical Biology, Mathematical Biosciences Institute, Ohio State University
9. Class lecture in the Seminar in Analysis, Cornell University

Membership in Professional Societies

- Member, American Society of Naturalists
- Member, Ecological Society of America
- Member, Society for Advancement of Chicanos/Hispanics and Native Americans in Science (SACNAS)
- Member, Society for Mathematical Biology

Professional Service

- Associate editor for *The American Naturalist*, 2017 - present.
- Member, Society of Mathematical Biology annual meeting, local organizing committee, 2017
- Manuscript reviewer for American Naturalist, Axios, Bulletin of Mathematical Biology, Differential Equations and Dynamical Systems, Ecology, Ecology Letters, Evolution, Journal of the Royal Society Interface, Journal of Theoretical Biology, Methods in Ecology and Evolution, Natural Resource Modeling, Oikos, PLoS Computational Biology, PLoS ONE, Proceedings of the Royal Society of London B: Biological Sciences, Theoretical Ecology, Theoretical Population Biology, and Theory in Biosciences
- Reviewer for the 2012 Alife 13 conference proceedings
- Volunteer judge for posters and presentations at SMB annual conference 2017; ESA annual conferences 2011, 2012, 2013; Georgia Tech Research and Innovation Conference 2012; and School of Biology Graduate Student Symposium at Georgia Tech 2011

Department of Biological Science
Florida State University

October 6, 2018

To whom it may concern,

I wish to apply for the assistant professor position in ecological/evolutionary theory.

I am a theoretical ecologist at Utah State University where I am an assistant professor in the Department of Mathematics and Statistics and a faculty associate of the Ecology Center. Previously, I was a postdoc in the School of Biology at Georgia Institute of Technology, part of which was funded by an NSF postdoctoral research fellowship. I completed my PhD in Applied Mathematics at Cornell University in 2011.

My research program focuses on how evolution and species interactions alter community-level dynamics. Three areas of focus are (1) eco-evolutionary theory, (2) epidemiological dynamics, and (3) species interactions and community dynamics. My work is in collaboration with empiricists, including Meghan Duffy (Michigan), Edd Hammill (Utah State), and Lutz Becks (University of Konstanz).

My work is published in top ecology and evolution journals. My work on eco-evolutionary theory is published in *PNAS*, *American Naturalist*, *Ecology Letters*, and *Ecological Monographs*; my work on epidemiological dynamics is published in *American Naturalist* and *Journal of Mathematical Biology*; and my work on community dynamics is published in *Ecological Monographs*, *Ecology*, and *Evolution*. This body of work has been recognized nationally, e.g., I received the 2011 prize for an outstanding theory paper from the Theory Section of the Ecological Society of America (ESA) and I was named an ESA Early Career Fellow in 2016 on the basis of my research in eco-evolutionary theory. In addition, I joined the editorial board of the *American Naturalist* in 2017.

My future research focuses on advancing eco-evolutionary theory, unifying it with theory for plastic adaptation, and developing theory for multi-host-multi-pathogen systems. The first two are the focus of a grant to be submitted in early 2019 and the latter is supported by an NSF grant; both involve collaborations with empiricists. Because my work focuses on ecological and evolutionary questions, I am interested in joining the Department Biological Science and in developing new collaborations with faculty in and outside of the Ecology and Evolution group who work on ecological, evolutionary and epidemiological questions.

I have experience teaching and mentoring graduates and undergraduates. I have taught theoretical ecology courses at Georgia Tech and USU, as well as grad/undergrad mathematics courses. I am interested in teaching ecological and evolutionary theory and modeling courses as well as core ecology, evolution, and community ecology courses. I have co-mentored 1 undergraduate and 4 graduate students and actively collaborate with graduate students; this has yielded 6 publications and 2 manuscripts. I am a leader of the USU Math Bio Group, where I mentor and train biology and math graduate and undergraduate students.

My recommendation letters are from my PhD advisor Stephen Ellner (Cornell), my postdoctoral advisor Joshua Weitz (Georgia Tech), and my collaborator Peter Abrams (Toronto).

Thank you for your consideration of my application. I look forward to hearing from you.

Sincerely,

Michael H. Cortez

Teaching Statement
Michael H. Cortez

As a theoretical ecologist who studies ecological and evolutionary processes, I am qualified and interested in teaching a range of courses at the undergraduate and graduate levels. At the undergraduate level I am qualified to teach lower-division courses (e.g., ecology, evolution, and calculus or statistics for biologists) as well as upper-level division courses such as advanced ecology and community ecology. I am also qualified to teach undergraduate and graduate mathematical biology courses, such as mathematical modeling and theoretical ecology, that cover topics including stage structured models, population genetics, game theory, population modeling, epidemiology, eco-evolutionary dynamics, and model fitting.

Teaching Aims and Philosophy

My goal is to help students develop critical thinking, problem solving, and quantitative skills that can be applied to biological problems. In the classroom, I do this via self-discovery based learning and emphasizing connections between course material and the literature.

Student-oriented and self-discovery based learning: In lectures and homework assignments, I use questions that (i) directly reinforce ideas covered in lecture, (ii) extend ideas from lecture, and/or (iii) ask students to hypothesize about or deduce relationships between concepts via specific problems. For example, when discussing the (de)stabilizing effects of predator functional responses, I use a set of assignments where students (i) verify that Type II functional responses are destabilizing, (ii) compare the results with Type III functional responses, and (iii) hypothesize about, and later show, what underlying biological and mathematical property determines the (de)stabilizing effects. Thus, by the end of the sequence the students have (i) reinforced their knowledge about the destabilizing effects of Type II functional responses, (ii) successfully extended those ideas to Type III functional responses, while learning about differences that can arise, and (iii) inferred how (de)stabilization depends on the derivatives of the functional forms. I also use computational labs where students explore course material using programs such as Matlab or the statistical package R. These labs expose students to how computational tools can aid in the exploration and understanding of biological phenomena. In the computational labs, students form and test hypotheses through repeated numerical experiments.

Connections between course material and scientific research: In all courses, I also connect lecture material with examples and applications from the literature. This emphasis on how course material applies generally to natural systems exposes students to how general principles and overarching concepts apply across systems. Upper level undergraduate and graduate courses also include student-led in-class discussions of published studies. In these discussions, students critically evaluate the studies and use material from class to suggest improvements or future areas of research. In addition to fostering communication skills, these discussions emphasize how course material relates to areas of current research. Finally, higher level courses include individual and group projects where project topics are chosen by the students. In the projects, students critically evaluate the studies, suggest future avenues of research, generate new hypotheses, and, test those hypotheses computationally. These projects foster problem solving and critical thinking skills and yield opportunities for students to apply lecture material to topics and systems beyond those studied in class.

Teaching Experience

I have taught three mathematical biology courses (one graduate course and two graduate/undergraduate cross-listed courses) and five graduate or undergraduate mathematics courses. My average course evaluate scores were 4.4/5 or greater (12, 13, and 4 students) and 4.1/5 or greater (40+ students) for the courses, respectively.

The mathematical biology courses were graduate/undergraduate courses cross-listed in the mathematical and biology departments at Georgia Tech and USU; the Georgia Tech class was co-taught with Joshua Weitz. The courses were attended by biology and applied math majors and PhD students. For all courses, I designed lectures that covered model development, analysis and interpretation; testing model hypotheses and predictions with experiments; and fitting models to experimental data. Lectures also included small group and full class discussions on studies from the literature and students' study systems. I also developed computational labs on predator-prey dynamics, within and between-host disease dynamics, eco-evolutionary dynamics, and model fitting. Through these labs, students explored, tested, and extended ideas presented in lecture. Example labs included analysis of functional response data, fitting models to time series data, and predicting the timing and size of recurring disease outbreaks. Each course culminated with student projects where each student extended a theoretical study from the literature to answer a biologically meaningful question.

Mentoring Experience

In mentoring, I encourage students to be independent and determine the direction of their research. In addition, I train students so that they have a solid foundation in the quantitative theory being used in their projects. As a graduate student and a postdoc, I co-mentored three undergraduate math students with Tim Pennings at Hope College and mentored a Georgia Tech undergraduate from the Biomedical Engineering Department. In addition to their research projects, the students completed a coursework component on dynamical systems theory and ecological modeling. As a postdoc, I co-mentored two physics graduate students with Joshua Weitz and collaborated with a School of Biology graduate student in Lin Jiang's lab. These projects have resulted in four publications (Jover et al. 2013, 2015; Taylor et al. 2015, Pu et al. 2017). While at USU, I have collaborated with biology PhD students from other universities (S. Patel, UC Davis; P. Clay, Rice) from which two manuscripts have resulted (Patel et al. and Cortez et al.). I am the advisor of one USU applied math student who is currently working on methods for estimating ecological and evolutionary time scales from time series data.

I am also a leader of the Mathematical Biology Group in the Math and Stats Department at USU. In that group, I mentor and train applied mathematics, statistics, and biology undergraduate and graduate students on running and performing empirical experiments, developing theoretical models and tools to analyze data, and evaluating existing models and modeling frameworks.

Statement about engaging and mentoring diverse students
Michael H. Cortez

I promote inclusion and diversity through my participation as a mentor in programs for junior and underrepresented groups in science, engaging in research with students from underrepresented groups, and public outreach activities.

I am a mentor in the local SACNAS chapter and the newly created Latinx Cultural Center at Utah State University (USU), both of which target underrepresented groups in science. I also have been a mentor for undergraduate and graduate students through conference sections, including the Theory Section of the Ecological Society of America and SACNAS. In these interactions I focus on encouraging and helping students explore careers and opportunities in science.

In the past and currently, I recruit and engage in research with students from underrepresented groups. As a postdoc at Georgia Tech, I mentored one undergraduate and two graduates students from underrepresented groups. At USU, my current group consists of one undergraduate student and one graduate student from underrepresented groups, and I collaborate with two graduate students from underrepresented groups. I actively recruit female and minority undergraduate and graduate students through my mentoring activities and by encouraging students taking my classes to consider doing research with me; both undergraduate researchers and two of the graduate students were recruited this way. Recruiting female and minority students is particularly important to me, because both groups represent only a small fraction of the students enrolled in science courses at Utah State. I will also be participating in the Native American STEM Mentorship program in Spring 2019. In this program, Native American students from USU's satellite campus in Blanding, UT participate in three one-week lab rotations. Because the Blanding campus mostly offers two-year degrees, one goal of the program is to use the research projects as encouragement for students pursue a four-year degree at the Logan (main) campus. My rotation is in collaboration with Edd Hammill (my experimental collaborator), and includes protist-flatworm experiments and numerical simulations focusing on how inducible defenses influence population dynamics.

While at Utah State University, I have also participated in public engagement through the USU Science Unwrapped program. That program involves monthly scientific lectures that are open to public and designed to be accessible middle and high schoolers. After the lectures, attendees interact with students and faculty presenting some aspect of their research at small booths. I have run small booths on disease dynamics and inducible defenses involving computer simulations, organisms from collaborators (e.g., induced and un-induced protists), and hands-on activities.

Research Statement
Michael H. Cortez

I am interested in identifying the underlying processes driving ecological and evolutionary patterns observed in natural communities. In many systems there may be multiple mechanisms that could explain observed patterns, but it may be difficult or impossible to experimentally test hypotheses about each mechanism. For example, for evolutionary studies it may be infeasible to genotype or phenotype individuals or conduct experiments over sufficiently long time scales. In these cases, mathematical and computational tools can help connect observed patterns to underlying processes. I use such tools to study (A) how evolution alters community-level dynamics, (B) how pathogen life-history traits and between-host and between-pathogen competition shape pathogen outbreak patterns, and (C) how community structure influences population dynamics. A central goal of my research is to develop theory that unifies and explains patterns observed across empirical systems.

I. CURRENT AND PAST WORK

A. Eco-evolutionary theory for predator-prey systems

My work on eco-evolutionary theory focuses on identifying how evolution alters community-level dynamics, how those effects depend on standing genetic variation and rates of evolution in populations, and how those effects compare with how plastic adaptation alters population dynamics.

In the absence of evolution, predator-prey oscillations have a particular pattern: peaks in prey abundance precede peaks in predator abundance by a quarter-period. However, virus-bacteria (*Escherichia coli* and their viruses [6]) and rotifer-algae (*Chlorella vulgaris* and *Brachionus calyciflorus* [31]) systems with rapid evolution of prey defense exhibit qualitatively different cycles like antiphase oscillations (half-period lag) and cryptic oscillations (one species cycles, the other remains constant). I have used eco-evolutionary models to explore how rapid evolution of prey defenses and/or predator offenses alter the ecological dynamics of predator-prey communities. The resulting studies [11, 16, 19] unified previous experimental and theoretical results [3, 23, 24, 31] and categorized the cycle types that arise via prey evolution, predator evolution, and coevolution. For example, the *PNAS* study [19] made a novel prediction of clockwise cycles: cycles where predators peaks precede prey peaks. These cycles are the reverse of classical ecological cycles and yielded new interpretations for time series from empirical systems [19]. In total, this work showed that cycle characteristics can be used to infer which species is evolving (e.g., clockwise cycles imply coevolution and antiphase cycles suggest prey evolution) and underlying trade-offs for defense/offense (e.g., antiphase cycles imply high costs and cryptic cycles imply low costs).

Additional experiments from rotifer-algae [5] and ciliate-bacteria [22] systems show that cyclic dynamics only arise if prey or predator genetic variation is sufficiently high. Building on the above, I explored how the amount of standing genetic variation in species influences populations dynamics. My recently published studies [12, 14, 17, 28] show how system stability can be decomposed into ecological, evolutionary, eco-evolutionary components and identify how genetic variation determines the relative strengths of those feedbacks. This work helps unify theoretical predictions about eco-evolutionary dynamics over different time scales, including traditional slow-evolution theory, e.g., adaptive dynamics theory [21], and more recent rapid evolution eco-evolutionary theory.

Adaptive responses in species can be evolutionary or plastic. Thus, I explored if evolution and plasticity differentially affect predator-prey dynamics. The resulting *Ecology Letters* paper [9] unified evolutionary and plastic responses under a single overarching adaptive theory and characterized the different effects evolution and plasticity have. For example, I showed that plasticity cannot drive antiphase or cryptic oscillations. These results suggest that characteristics of predator-prey oscillations can be used to infer whether predators or prey are evolving or responding plasticly to their environment. This paper was awarded the 2011 prize for an outstanding paper in ecological theory by the Theoretical Ecology Section of the Ecological Society of America.

B. Epidemiological theory for host-pathogen systems

My work on epidemiological systems focuses on how pathogen life-history traits and between-host and between-pathogen competition shape pathogen outbreak patterns.

Invasive hosts can cause pathogen prevalence in native hosts to increase (amplification) or decrease (dilution). Current theory predicts that amplification/dilution depends on the host competencies and population densities [25], but does not account for between-host competition. As part of a study published in *American Naturalist* [30] that combined experimental and theoretical approaches, I developed new theory on how between-host competition can alter amplification/dilution of disease. Using parameterized models, my theory helped explain how amplification and dilution of a fungal pathogen (*Metschnikowia bicuspidata*) in daphniid hosts (*Daphnia dentifera* and *D. lumholtzi*) was driven by asymmetric intra and interspecific host competition. Importantly, this new theory helped resolve seemingly contradictory experimental results at different scales (individual-level infection experiments vs. population-level mesocosm outbreak experiments). This work is a first step in understanding how between-host competition influences pathogen outbreak patterns and is a step toward building epidemiological theory for multi-host-multi-pathogen systems.

Identifying a pathogen's transmission pathway from population-level data is an important problem in applied epidemiology. Using Susceptible-Infected-Recovered (SIR) type models, I investigated if and when direct (contact with infectious conspecifics) and environmentally mediated (pathogen exposure in the environment) transmission routes could be inferred by fitting epidemiological models to time series data. The resulting study [18] showed that while the transmission mechanism cannot be inferred via model fits to data when pathogen persistence in the environment is short, it may be possible when the pathogen persists for long periods. Using this theory, I revisited a previous study on Chronic Wasting Disease [27] and found that the transmission mode could not be inferred from the data as originally claimed. This work showed how and when mechanistic differences in pathogen transmission can alter the community dynamics of epidemiological systems.

Selection can favor pathogens with high, intermediate, or low virulence. Previous theoretical studies (e.g, [4]) argue that pathogen evolution maximizes the basic reproductive number ($\mathcal{R}_0$), i.e., selection favors strains that maximize spread in completely susceptible populations. However, eco-evolutionary feedbacks are expected to inhibit $\mathcal{R}_0$ maximization [26]. Hence, I explored how pathogen life-history traits (e.g., transmission mode and density dependent trade-offs) affect pathogen evolution and promote or inhibit $\mathcal{R}_0$ maximization. This *Journal of Mathematical Biology* study [10] identified restrictive biological conditions for $\mathcal{R}_0$ maximization (density-independent trade-offs), connected those mathematical results to the life-history traits of pathogens and their hosts, and highlighted the ways in which eco-evolutionary feedbacks influence pathogen evolution.

C. Community ecology theory

This body of work focuses on how counter-intuitive population dynamics exhibited by a particular species are shaped by the interactions between other species in their community. For example, increased harvesting of the invasive smallmouth bass (*Micropterus dolomieu*) can cause in an increase in population abundance [32], a counter-intuitive response called a hydra effect [1]. My work [2, 13, 15], including publications in *Ecological Monographs* and *Ecology*, identified a general condition driving hydra effects in predator-prey and other interaction webs. Specifically, a species exhibits a hydra effect if its community cannot stably coexist when its density is fixed. This means (a) the dynamics and presence of 'hydra effect'-species are necessary for community stability and coexistence and (b) hydra effects are driven by the interactions between all other community members. I used this condition to identify mechanisms driving hydra effects in particular ecological communities, e.g., in predator-two-prey systems, predator hydra effects occur when the prey cannot coexist in the absence of the predator (predator-mediated coexistence). This work unified existing theory on hydra effects and revealed many new mechanisms that give rise to hydra effects.

II. FUTURE WORK

Building on this research program, I plan to continue investigating how species adaptation and interactions shape the ecological and epidemiological dynamics of natural systems. Because my work is motivated by phenomena observed in natural systems, I collaborate with experimentalists (M. Duffy, University of Michigan; L. Becks, Konstanz; and E. Hammill, Utah State) and look forward to initiating new collaborations at Florida State University. My goal is to develop models and theory in collaboration with empiricists to test hypotheses about how ecological and evolutionary processes shape the dynamics of communities.

A. Ecological theory for plastic adaptation

Plastic responses can be behavioral or morphological in nature, differ in their speed and timing, and be affected by multiple cues (e.g., cues from predators or conspecifics). Mechanistic differences between responses could have important effects at the community level, e.g., different mechanisms may amplify or dampen predator-prey cycles. Building on my *Ecology Letters* study [9], I plan to investigate how differences in mechanism and timing influence the effects plastic responses have on the community dynamics of predator-prey systems. In collaboration with an empiricist (Edd Hammill, USU), I will develop different mechanistic models and test theoretical predictions via mesocosm experiments involving microbial communities. To complement my work on coevolution, I will also investigate how co-plasticity and coevolution differentially affect community-level ecological dynamics. This work will yield insight how plasticity alters population-level dynamics and unify theory on how evolution and plasticity affect community dynamics.

B. Multi-host-multi-pathogen theory

Most pathogens infect multiple host species and most host species are infected by multiple pathogens [8, 29]. However, most epidemiological theory ignores the effects of between-host and between-pathogen competition on disease outbreak patterns [29]. Building on recently published [30] and submitted [7] studies, I plan to develop new epidemiological theory that explains (i) how between-host competition alters indirect effects between pathogens that do not directly compete and (ii) how between-host and between-pathogen competition affects pathogen outbreak patterns. In addition, this work will explain how differences in transmission route affect predictions about between-host and between-pathogen direct and indirect effects. This work is funded by the NSF (through the Division of Environmental Biology) and is in collaboration Meghan Duffy (Michigan), whose daphniid-pathogen system will be used to test theoretical predictions. In total, this work will develop new epidemiological theory that explains how between-host and between-pathogen interactions and differences in transmission route shape pathogen outbreak patterns.

C. Eco-evolutionary theory for host-pathogen systems

Much work on pathogen evolution focuses on evolution over long evolutionary time scales [26]. However, host and/or pathogen evolution can occur over short ecological time scales (e.g., during a single epidemic [20]). I plan to extend my work on predator-prey systems [12, 16, 19] to ask how host and pathogen evolution affect the outbreak patterns of host-pathogen systems. First, I plan to explore how selection in pathogen populations changes over the course of an epidemic and if signatures of evolution can be observed in epidemiological time series. This will identify how differences in subsequent epidemics be used to infer evolutionary change in the pathogen. Second, motivated by studies of *Daphnia* evolution driven by its fungal pathogen [20], I plan to explore how genetic variation in host populations affects outbreak patters and host-pathogen community dynamics. This project will focus on how the evolution of tolerance and resistance differentially affect host-pathogen dynamics. In total, this body of work will begin to unify and explain how the dynamics of natural communities are shaped by genetic variation in host and pathogen populations.

References

[1] P. A. Abrams, *When does greater mortality increase population size? the long history and diverse mechanisms underlying the hydra effect*, Ecology Letters, 12 (2009), pp. 462–474.

[2] P. A. Abrams and **Cortez, M.H**, *The many potential interactions between predators that share competing prey*, Ecological Monographs, 85 (2015), pp. 625–641.

[3] P. A. Abrams and H. Matsuda, *Prey adaptation as a cause of predator-prey cycles*, Evolution, 51 (1997), pp. 1742–1750.

[4] R. M. Anderson and R. M. May, *Coevolution of hosts and parasites*, Parasitology, 51 (1982), pp. 1742–1750.

[5] L. Becks, S. P. Ellner, L. E. Jones, and N. G. H. Jr., *Reduction of adaptive genetic diversity radically alters eco-evolutionary community dynamics*, Ecology Letters, 13 (2010), pp. 989–997.

[6] B. J. M. Bohannan and R. E. Lenski, *Linking genetic change to community evolution: insights from studies of bacteria and bacteriophage*, Ecology Letters, 3 (2000), pp. 362–377.

[7] P. Clay, **M.H. Cortez**, M. Duffy, and V. Rudolf, *Priority effects within co-infected hosts alter prevalence relationships between parasites at the host population scale*, (submitted).

[8] S. Cleaveland, M. K. Laurenson, and L. H. Taylor, *Diseases of humans and their domestic mammals: pathogen characteristics, host range and the risk of emergence*, Philosophical Transactions of the Royal Society of London B, 356 (2001), pp. 991–999.

[9] **M.H. Cortez**, *Comparing the qualitatively different effects rapidly evolving and rapidly induced defences have on predator-prey interactions*, Ecology Letters, 14 (2011), pp. 202–209.

[10] ——, *When does pathogen evolution maximize R0 in well-mixed host-pathogen systems?*, Journal of Mathematical Biology, 67 (2013), pp. 1533–1585.

[11] ——, *Coevolution-driven predator-prey cycles: predicting the characteristics of eco-coevolutionary cycles using fast-slow dynamical systems theory*, Theoretical Ecology, 8 (2015), pp. 369–382.

[12] ——, *How the magnitude of prey genetic variation alters predator-prey eco-evolutionary dynamics*, American Naturalist, 188 (2016), pp. 329–341.

[13] ——, *Hydra effects in discrete-time models of stable communities*, Journal of Theoretical Biology, 411 (2016), pp. 59–67.

[14] ——, *Genetic variation and the drivers of eco-coevolutionary predator-prey cycles*, Ecological Monographs, 88 (2018), pp. 353–371.

[15] **M.H. Cortez** and P. Abrams, *Hydra effects in stable communities and their implications for system dynamics*, Ecology, 97 (2016), pp. 1135–1145.

[16] **M.H. Cortez** and S. Ellner, *Understanding rapid evolution in predator-prey interactions using the theory of fast-slow dynamical systems*, The American Naturalist, 176 (2010), pp. E109–E127.

[17] **M.H. Cortez** and S. Patel, *The effects of predator evolution and genetic variation on predator-prey population-level dynamics*, Bulletin of Mathematical Biology, 79 (2017), pp. 1510–1538.

[18] **M.H. Cortez** and J. Weitz, *Distinguishing between indirect and direct models of transmission using epidemiological time series data*, American Naturalist, 181 (2013), pp. E109–E127.

[19] ——, *Coevolution can reverse predator–prey cycles*, Proceedings of the National Academy of Sciences USA, 111 (2014), pp. 7486–7491.

[20] M. A. Duffy, C. E. Brassil, S. R. Hall, A. J. Tessier, C. E. Cáceres, and J. K. Conner, *Parasite-mediated disruptive selection in a natural daphnia population*, BMC Evolutionary Biology, 8 (2008), pp. 1–9.

[21] S. A. H. Geritz, É. Kisdi, G. Meszéna, and J. A. J. Metz, *Evolutionarily singular strategies and the adaptive growth and branching of the evolutionary tree*, Evolutionary Ecology, 12 (1998), pp. 35–57.

[22] T. Hiltunen and L. Becks, *Consumer co-evolution as an important component of the eco-evolutionary feedback*, Nature Communications, 5 (2014), p. 5226.

[23] L. E. Jones, L. Becks, S. P. Ellner, N. G. Hairston, Jr., T. Yoshida, and G. F. Fussmann, *Rapid contemporary evolution and clonal food web dynamics*, Philosophical Transactions of the Royal Society of London B: Biological Sciences, 364 (2009), pp. 1579–1591.

[24] L. E. Jones and S. P. Ellner, *Effects of rapid prey evolution on predator-prey cycles*, Journal of Mathematical Biology, 55 (2007), pp. 541–573.

[25] F. Keesing, R. D. Holt, and R. S. Ostfeld, *Effects of species diversity on disease risk*, Ecology Letters, 9 (2006), pp. 485–498.

[26] J. A. J. Metz, S. D. Mylius, and O. Dieckmann, *When does evolution optimize?*, Evolutionary Ecology Research, 10 (2008), pp. 629–654.

[27] M. W. Miller, N. T. Hobbs, and S. J. Boots, *Dynamics of prion disease transmission in mule deer*, Ecological Applications, 16 (2006), pp. 2208–2214.

[28] S. Patel, **M.H. Cortez**, and S. J. Schreiber, *Partitioning the effects of ecology, evolution, and eco-evolutionary feedbacks on community stability*, American Naturalist, 191 (2018), pp. 381–394.

[29] T. Rigaud, M.-J. Perrot-Minnot, and M. J. F. Brown, *Parasite and host assemblages: embracing the reality will improve our knowledge of parasite transmission and virulence*, Proceedings of the Royal Society of London B: Biological Sciences, 277 (2010), pp. 3693–3702.

[30] C. L. Searle, **M.H. Cortez**, K. K. Hunsberger, D. C. Grippi, I. A. Oleksy, C. L. Shaw, S. B. de la Serna, C. L. Lash, K. L. Dhir, and M. A. Duffy, *Population density, not host competence, drives patterns of disease in an invaded community*, American Naturalist, 188 (2016), pp. 554–566.

[31] T. Yoshida, L. E. Jones, S. P. Ellner, G. F. Fussmann, and N. G. Hairston, Jr., *Rapid evolution drives ecological dynamics in a predator-prey system*, Nature, 424 (2003), pp. 303–306.

[32] E. F. Zipkin, P. J. Sullivan, E. G. Cooch, G. E. Kraft, B. J. Shuter, and B. C. Weidel, *Overcompensatory response of a smallmouth bass (micropterus dolomieu) population to harvest: release from competition?*, Canadian Journal of Fisheries and Aquatic Sciences, 65 (2008), pp. 2279–2292.