Cornell University

Department of Ecology and Evolutionary Biology
Cornell University
Corson Hall
Ithaca NY 14853-2701

October 20, 2018

Search Committee, Ecological/Evolutionary Theory
Florida State University

Dear committee members:

I am writing to give my strongest possible recommendation for Michael Cortez, who has applied for your tenure track opening in Ecological/Evolutionary Theory.

Michael is one of the best graduate students I have ever advised, possibly the very best. An honest letter about Michael has to use a lot of superlatives, enough to cast doubts on my credibility. I've had other students who were creative and innovative, some with a good nose for projects that are really worth doing, one who might be Mike's equal at math (though the case for that is getting harder every year), and a few others who could consistently get a project done and write a good first draft without fuss or delay – but the whole package in one person? Only Mike.

Michael's research focus is applications of dynamical systems theory to ecology and evolution. Michael was *de jure* my PhD advisee at Cornell in the Applied Mathematics program. But *de facto* he was co-advised by John Guckenheimer in the Math Department (Cornell does not formally allow PhD co-advisors), and he took the dynamical systems courses (and prerequisites) that John requires of his own PhD students. Michael's thesis focused on the interaction of ecological and evolutionary dynamics when they occur on the same time scale. Twenty years ago, most ecologists and evolutionary biologists would have said that evolution is by far the slower process. Now, starting with the celebrated work on Darwins finches but with dozens of other empirical examples, we know that ecologically important traits can change dramatically within a few generations. Accommodating that reality, and understanding its consequences, makes for challenging mathematics.

Two excellent publications came out of Mike's thesis. The first, in *American Naturalist*, used slow-fast dynamical systems theory to study a general model for predator-prey dynamics when prey rapidly evolve defenses in response to predation, and rapidly lose those defenses when predators are scarce, in favor of better competitive ability. He used his results to unify the existing literature on eco-evolutionary predator-prey dynamics, and to discover a wider array of possible dynamics in such systems than anybody had previously realized – including me, although I had worked in that area for over 10 years.

The second paper contrasted the effects of rapid trait evolution versus rapid phenotypic plasticity in prey species. Frustrated with a bifurcation analysis that was growing tedious, Mike decided to think about plasticity instead of rapid evolution for a while. Two weeks later, he came in to explain his ideas and ask me if this was worth working on. I said "yes" and sent him out with some pointers to the literature. Soon he had developed a general framework that encompassed much of the previous literature and was on his way to a general analysis that would unify many previously unconnected results and then push things forward. The paper was published in *Ecology Letters*, the top subject-area journal in ecology, and received the 2012 annual "Best Paper" award from the Theoretical Ecology section of the Ecological Society of America.

Mike has continued to do excellent work – far too much for me to comment on all of it here. His 2012 paper in *J. Math Biology* is a fundamental contribution to the theory of pathogen virulence evolution. It once again unifies and extends previous work, in this case theory about if and when the evolution of pathogen virulence is characterized by maximization of some fitness measure. He jumped into territory worked over by some of the biggest names in mathematical modeling of infectious diseases (such as Odo Diekmann and Mats Gyllenberg), and made a substantial advance. Similarly, his 2013 *J. Theor. Biology* paper with Jover and Weitz greatly generalized the dominant Kill the Winner model for phage-bacteria communities, showing that actually observed patterns of specificity (including nested infection networks) could also produce stable coexistence of multiple bacteria and phages. His 2014 PNAS paper showed that predator-prey or host-pathogen coevolution can explain the observations (in field and laboratory systems) of cycles in which peaks of pathogen/predator abundance *precede* peaks of host/prey abundance, exactly the opposite of what *any* conventional model predicts. Mike's results offer a simple explanation built on well-established mechanisms: the victims can defenses against attack/infection, and predators/pathogens can evolve counter-adaptations, but both those traits are lost when they aren't useful. The findings in that paper are completely unexpected, but easy to understand once you see how it happens, and it just might explain several otherwise baffling data sets.

Mike's 2016 *American Naturalist* paper represents, I think, another real breakthrough in the theory of eco-evolutionary dynamics. Mike's analysis provides a connection between the rapid-evolution limit and the slow-evolution limit (called *Adaptive Dynamics* by its proponents) in models for predator-prey coevolution, so that knowing what happens in the two much simpler limits lets you predict what happens when ecology and evolution are on comparable time scales. That paper again shows off Mike at his best, doing technically challenging math to address a question arising from empirical observations. The empirical observations are contradictory experimental results about whether higher prey genetic variation is stabilizing or destabilizing for the population dynamics. Previous work was limited to some piecemeal results about specific models. That's all well and good, Mike writes, but to really understand how standing levels of genetic variation affect predator-prey dynamics, we need a general theory. The result is, once again, a new general analysis that unifies and extends previous work by people of very good repute in theoretical ecology such as Yoh Iwasa, Peter Abrams, and me. Mike's new *Ecological Monographs* paper extends this work to consider both prey and predator levels of genetic variation, while Patel, Cortez and Schreiber in *American Naturalist* extend Mike's analyses to multiple traits in multiple co-evolving species.

The result of this sustained effort is emergence of a general theory for the coupled dynamics of interacting populations and the traits that determine the strength of those interactions – and at each step, Mike has been the key innovator or one of the key innovators. It's challenging math, and scientifically relevant, as evidenced by the Ecological Society of America selecting Mike as an Early Career Fellow.

In short, since the start of his career Michael has given every indication of being a major talent who will continue to make significant contributions at the interface of applied mathematics with ecology and evolution. He has drive, focus, the ability to identify important questions, and mathematical abilities far beyond what "theoretical ecologist" usually signifies. I hope you take his application very seriously, and I can't imagine that you would regret a decision to interview or hire him.

Sincerely,

Stephen P. Ellner
Horace White Professor
Department of Ecology & Evolutionary Biology, and Center for Applied Mathematics

Prof. Joshua Weitz
School of Biological Sciences
Interdisciplinary Graduate Program in Quantitative Biosciences
Atlanta, Georgia 30332-0230 USA
Phone: (404) 385-6169
Email: jsweitz@gatech.edu

October 15, 2018

Search Committee in Ecological/Evolutionary Theory
Department of Biological Science
Florida State University

To whom it may concern,

It is my pleasure to offer my highest recommendation to **Michael H. Cortez** for a Tenure-Track Assistant Professor position in Biological Science at FSU. Prof. Cortez is an exceptionally talented and creative theoretical ecologist focusing on foundational problems at the interface of ecology, evolution, disease dynamics, and dynamical systems theory, with a focus on pathogen dynamics. In the past few years he has made important discoveries on coevolutionary dynamics (published in Ecology Letters, American Naturalist, Bulletin of Mathematical Biology, amongst others), in the analysis of epidemiological models (published in American Naturalist and the Journal of Mathematical Biology), and has made a fundamental discovery on the nature of predator-prey cycles given rapid coevolution (the core results of which are published in PNAS, Theoretical Ecology & Am Nat). He has a significant body of work laid out that will lead to continued productivity in the years to come. Even as a postdoc, I considered Michael a peer and colleague who would soon direct his own research group. Michael is now an Assistant Professor in Mathematics at Utah State where is also a Faculty Associate in the Center for Ecology. Since starting at Utah State in 2014 he has had more than 10 new papers accepted/published – the majority of which he led or co-led. He has also recently secured his first major NSF grant as lead PI of a collaborative project on multi-host, multi-pathogen theory. He is at the same level as top Assistant Professors in Mathematical Biology originally trained in Simon Levin's Theoretical Ecology group at Princeton, where I did my postdoctoral training.

In thinking about what kind of scholar Michael will become, it is important to point out from the outset: Michael is already a burgeoning leader in the field of eco-evolutionary dynamics. He was recognized in 2016 as an Early Career Fellow from the Ecological Society of America for his innovative research on eco-evolutionary dynamics within predator-prey systems. His thesis work on eco-evolutionary dynamics in predator-prey systems is exceptional and demonstrates a command of the history of research in this area and ways in which new methods can help disentangle different modes by which traits change. His article in Ecology Letters (the top-journal in Ecology) is highly impactful, as it provides traction into what had seemed like an intractable problem: how to distinguish between evolution and inducible responses in ecological dynamics. Michael was awarded the Best Paper in Theoretical Ecology from the Ecological Society of America on the basis of results from this manuscript. This first result naturally leads to many other interesting problems at the interface of ecological and evolutionary dynamics. For example, Michael organized a minisymposium on this topic at the Society for Mathematical Biology Annual Meeting in 2013, including an international lineup of speakers (Troy Day, Alvaro Sanchez, & Masato Yamamichi).

Indeed, Michael is already a dynamic, interactive colleague. He impresses during visits and one-on-one conversations because he can engage thoughtfully on nearly any topic at the interface of dynamical systems and biology. He understands and has insights into the mathematics associated with predator-prey dynamics, epidemiological dynamics and evolutionary theory. He understands the biology of these systems and can leverage them to make general conclusions. He would be a valuable colleague and collaborator to ecologists, epidemiologists, evolutionary biologists and applied mathematicians. Below, I describe Michael's some of recent accomplishments in both research and teaching, focusing on those projects overlapping with his stay in my group as a postdoctoral fellow from 2010-2014, updated with his work as faculty at Utah State.

Distinguishing between indirect and direct modes of transmission using epidemiological time series

Identifying the mode of transmission of a pathogen (or causative agent) is a key priority in the study of infectious disease. For example, it remains an open question if there exists qualitative (or quantitative) signatures in disease dynamics when pathogens (or causative agents) are directly vs. indirectly transmitted. To address this question, Michael considered a broad class of models used to describe infectious disease dynamics with indirect and direct transmission. He then utilized fast-slow systems theory to characterize the dynamics that arise in both models. This project has led to two major conclusions as described in Cortez and Weitz (American Naturalist, 2013). First, we discovered that indirect vs. direct transmission are generally indistinguishable within classic epidemiological models. In other words: it is possible that two alternative modes of transmission lead to (nearly) equivalent time series. Michael applied this theory to a prior case study of chronic wasting disease in mule deer that had concluded, based on the structure of population level data, that transmission must be indirect. Michael derived an alternative model that fit equally well to time series data of chronic wasting disease in mule deer, albeit with fewer parameters in a direct transmission model. Hence, we showed that previous inferences regarding transmission pathways may not be as robust as claimed. However, Michael did find instances in which qualitative indicators in prevalence trajectories could serve as signatures of transmission mechanism, e.g., the timing of peaks in measured time series. This type of theory-grounded general result with a practical significance typifies Michael's style and approach to science.

Coevolution Drives Clockwise Predator-Prey Cycles

Michael has a long-standing interest in the shape of predator-prey cycles. The hallmark of predator-prey cycles is that the prey population should peak in abundance before a subsequent predator population peak. This timing of population peaks reflects basic biology: predator consume prey, hence when prey are abundant, predators consume them at higher rates, leading to decreases in prey and increases in predator populations. The timing of predator-prey peaks was first predicted by Lotka and Volterra nearly 90 years ago and has been observed in multiple datasets since (including the canonical hare-lynx dataset). However, existing predator-prey theory nearly invariably assumes that the individuals in a population are phenotypically identical. Michael recognized that if a population was comprised of different subtypes, and if the frequency (or the number) of such subtypes could change on similar time scales as the population densities, then measurements of total prey and predator populations might appear quite different than canonical predator-prey cycles. This turned out to be the case. Michael has demonstrated that predator populations can peak in abundance *before* prey populations peak in abundance. He illustrated this conceptual idea using a discrete trait model where predators and prey are comprised of two different subpopulations with life history trait trade-offs, e.g., predators with relatively high and low-offensive ability, and prey with relatively high and low-defensive ability. He then generalized this model, by extending quantitative genetics frameworks to coevolutionary predator-prey dynamics – and again was able to demonstrate when and why inverted cycles are expected to appear. Finally, he systematically explored time series datasets and now has accumulated multiple lines of empirical evidence, including in microbial systems, for exactly this type of inverted predator-prey dynamics. In my view, Michael's analysis is a *tour de force* which will have long-standing impact (Cortez & Weitz, Proc. Natl. Acad. Sci. USA, 2014). The manuscript reflects Michael's independence and creativity in identifying and difficult problems, utilizing innovative theory to provide insight into the problem at hand, and integrating predictions with empirical data. His follow-up work generalizes and extends these original results and will provide key motivation for new experiments (Cortez, Theor. Ecol, 2015). New theoretical results published in BMB and Am. Nat. in 2017 show the impact and potential of this core component of Michael's insights. Already Michael is beginning to consider how coevolution can change more than just population dynamics features but community properties, like productivity and stability. These new directions will deepen the extent to which the ecological community continues to integrate models that Michael has developed.

Teaching Theoretical Ecology and more

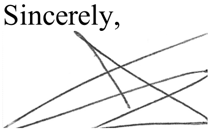
Michael and I co-taught Theoretical Ecology (BIOL 4422/6422) in Spring 2012, a cross-listed undergraduate and graduate class in the School of Biology at Georgia Tech. I had taught the course in 2008 and 2010 – but this was the first time a postdoctoral scientist had acted as co-instructor. Michael was not required to teach as part of his postdoctoral fellowship duties, but specifically requested to do so. He was an excellent instructor, developing new course materials for topics related to eco-evolutionary dynamics – including a total of 12 new lectures. These new lectures covered a range of topics including: adaptive dynamics; models of rapid evolution; neutral theory of biodiversity and biogeography, and inferring model structure from data. He did an excellent job of communicating complicated mathematical concepts, of introducing datasets, and of leading students in their capstone independent projects. His lectures notes are of high quality – indeed, I plan to utilize them in future years (giving him due credit of course) when I teach modules from his list of topics. Michael was also rated highly by the students in final evaluations: receiving a 4.4/5 in answer to the final question in the assessment survey that judges overall effectiveness of the instructor. Overall, given Michael's training in applied mathematics and extensive interactions with biologists, he is prepared to teach ecology and evolution courses, mathematical modeling in biology courses, and advanced graduate courses in evolution and ecology.

As should be evident, Michael is an innovative and creative scholar. He will also be a strong mentor and colleague – evidently capable of balancing the many responsibilities that junior faculty must handle. At Georgia Tech, Michael helped co-mentor two PhD candidates in my group, Luis Jover and Bradford Taylor, whose research emphases are in the area of viral-host interactions. Michael took this mentoring seriously, and, with me, helped advise Luis as he researched and completed his first two scientific manuscripts on viral-host dynamics in complex communities (Jover, Cortez and Weitz, J. Theor. Biol., 2013; Jover, Flores, Cortez & Weitz, Sci Reports, 2015). This is a very important process in the development of a student. I asked that Michael meet with Luis once a week, however I would see them talking science far more often. Michael similarly helped Bradford Taylor complete his first science-oriented manuscript on the ecological dynamics of the viruses of phage (so-called 'virophage') (Taylor, Cortez and Weitz, JTB, 2014). In addition, Michael was always available to help students in the group and served as a judge in undergraduate scientific competitions. This is consistent with his prior outreach efforts at prior institutions and reflects his commitment to teaching and service. Michael has all the characteristics of an excellent teacher and mentor to students of varied backgrounds and disciplinary training. It is clear he has been able to scale this up as an independent PI through mentoring and extramural grant proposals. For example, this past summer, Michael was awarded a NSF collaborative grant on developing mechanistic multi-host, multi-pathogen theory, for which he is the lead PI.

To conclude, Michael's research is novel and fits into an area of growing excitement regarding the synthesis of ecological, epidemiological, and evolutionary dynamics. Michael will be successful in attracting external support for these goals, given that he can identify important problems, solve hard problems by combining theory and computation, and explain his results in terms that are meaningful to empirically-focused colleagues focusing on ecological and evolutionary systems research from a variety of perspectives. Michael was a nationally recognized PhD student at Cornell, a nationally recognized postdoc at Georgia Tech, and is already a nationally recognized professor at Utah State. His research, teaching, and service to the mathematical biology community will continue to enrich students and colleagues. He has my highest recommendation and would be an ideal fit for this position. I urge you to give him your most serious consideration.

Please do not hesitate to contact me if you require further information.

Sincerely,



Joshua S. Weitz
Professor of Biological Sciences
Courtesy Professor of Physics
Founding Director of the Interdisciplinary Graduate Program in Quantitative Biosciences
Georgia Institute of Technology

October 10, 2018

Dear Members of the Search Committee,

I am writing to give my strongest recommendation for Dr. Michael Cortez for the faculty position in Ecological/Evolutionary Theory at Florida State. I have known Mike since 2010, when he began his postdoc at Georgia Tech (where I was a faculty member at the time) working with Joshua Weitz. Mike and I now collaborate on projects related to the ecology and evolution of infectious diseases, with one paper published, one in press, and others in preparation. Working with Mike has been fantastic. He is exceptionally bright and thinks deeply about foundational questions in ecology and evolution. I think he is one of the top young ecologists, and that he will have a very big impact on the field. He is a rising star.

Mike and I collaborate on questions related to multihost-multiparasite interactions. Most hosts can be infected by multiple parasites, and most parasites can infect multiple hosts. Despite that, most studies have focused on single host-parasite pairings. In my opinion, this means we have a very limited understanding of host-parasite interactions in nature. There is much interesting, important work to do on the topic of multihost and multiparasite interactions, but the theoretical foundation for much of this work is lacking. Mike has already begun to fill in those gaps, and I'm confident that he will continue to do foundational work in this area.

Mike has very impressive math skills (as you'd expect from someone who is currently a faculty member in a math department!) and is also very good at identifying core biological questions to which to apply those skills. As just one example: Mike has realized that he can use fast-slow systems theory to unite theory on directly and environmentally transmitted parasites; such a unification will be extremely valuable to epidemiologists and disease ecologists.

You will be able to see from his CV that Mike has an exceptional publication record, publishing very impressive papers in top journals. There is no question that he is one of the top young ecologists. (Indeed, he was recognized as such when he was named an Early Career Fellow of the Ecological Society of America.)

Mike is a theoretician who does not, on his own, do any empirical work. However, Mike is very good at working with empiricists such as myself. He has pushed my work in new directions and has made my empirical studies stronger and much more broadly applicable. To give an example: Mike is second author on our 2016 paper in *American Naturalist*. His contributions to that paper were essential and, without them, the study would not be nearly as interesting or useful to understanding the ecology of multihost parasites. We were interested in understanding how adding an invasive host would influence a focal host-parasite interaction. To test that, we did beaker-level studies on individuals, plus community-level studies in 15L mesocosms. The results of those two

Biological Sciences Building, 1105 North University
Ann Arbor, MI 48109-1085
Phone: 734-763-3658
email: duffymeg@umich.edu
Please recycle

studies seemed at odds with one another. As we were trying to figure out what was going on, I approached Mike with the data, and he worked on theory that helped us to explain the discrepancy. (The answer: competitive interactions between the hosts are more important than differences in disease competence.) Importantly, Mike went beyond simply trying to help us understand our data, doing the work needed to help us understand more generally how asymmetries in intra- and interspecific competition can influence disease outcomes.

Mike is now one of my primary collaborators. He is the lead PI on our new NSF grant that just began this summer. This work links empirical work my lab has been doing on coinfections and multiparasite interactions with theory done by Mike. Together, we are aiming to build to a general understanding of multihost-multiparasite interactions, and to understand how host and parasite diversity influence those interactions.

In all of my interactions with Mike, I have been struck by how smart he is, how deep his knowledge of ecology and evolutionary biology are, and his incisiveness in approaching questions. His clarity of thinking is apparent both in his writing (his first drafts are very impressive!) and in his seminars (which are very easy to follow). He is also very easy to interact with, and would make an excellent departmental colleague and citizen. He is also very easy to collaborate with; I know he has also developed collaborations at Utah State.

Mike has already shown that he can successfully mentor students, including those from underrepresented groups. Mike is a co-leader of the mathematical biology group at Utah State. That group has 13 students whose interests span biology, applied math, and statistics; 8 of those students are from traditionally underrepresented groups. During his time at Georgia Tech, he mentored undergraduates and graduate students, again, with several from underrepresented groups. (Mike is an underrepresented racial/ethnic minority himself.) Moreover, I have watched him work with two graduate students in my lab. Mike has done a really good job of helping them develop their interests and skills at the math-bio interface. One publication from these efforts is currently in press at Oikos, a strong ecological journal.

I could continue to go on about how excellent Mike is, but, knowing what this process is like from the search committee side, I understand that what you are looking for is not simply an indication of whether someone is good, but whether someone is one of the best. Mike is one of the best. I would be thrilled to have him as a colleague.

I know that there can also be discussions in these search committee meetings about whether someone who already has a faculty position is really likely to want to move. Mike is movable, and this position seems like an excellent match.

Sincerely,

Meghan Duffy
Professor

Department of Ecology and Evolutionary Biology 25 Harbord St.
University of Toronto Toronto, Ontario, Canada M5S 3G5

October 13, 2018

Florida State University
Search Committee, Ecological/Evolutionary Theory

To Whom It May Concern:

I am writing this letter in support of Michael Cortez's application for the recently advertised position in prokaryotic biology. Michael started his first academic position four years ago, and is already one of the most accomplished and most promising young mathematical ecologists/evolutionists I have encountered during my career. A good deal of his work has dealt with the dynamics of disease organisms, and much of his basic theory on coevolution has been tested using communities of organisms that are small enough to have replicate communities in the laboratory. There are at best a partial handful of people at his career stage who have a comparable breadth and depth of interests and published work in both ecological and evolutionary theory. I will begin by describing how I came to know Michael and his work, and then go into more detail on the contributions.

Because one of Michael's main areas of work (evolution in predator-prey systems) is also one of my main interests, I've known about his work since I read his 2010 article on that topic in The American Naturalist. I was very impressed by that paper and his subsequent 2011 Ecology Letters article comparing the nature of population cycles generated by the evolution of prey defenses and cycles caused by the induction of phenotypically plastic prey defenses (even though I have some disagreements with the latter). Both of these articles were based on his thesis work with Steve Ellner at Cornell. I first met Michael at the 2012 annual meeting of the Ecological Society of America, where we had a long talk about modeling rapidly adapting traits in models of interacting species. We eventually decided to carry out some joint work. This led to a week-long visit to Toronto in the fall of 2013, which was followed by numerous Skype calls, emails, and ultimately three papers that have appeared over 2015-2016. I am hoping to continue this collaboration in the future; we probably would have done so already if I had not recently devoted a great deal of time looking for and getting settled in a new home city.

Michael has a broad background in both applied mathematics and ecology/evolution. All of the publications from his Ph.D and postdoctoral work are substantial pieces of work published in excellent journals. So far as I know, he is the first person to get the Ecological Society's Theory Section 'Best Paper of the Year' award while still a graduate student. He also received a highly competitive NSF postdoctoral fellowship for his postdoctoral position at Georgia Tech and was awarded a 4-year Early Career Fellowship from the Ecological Society of America. He now has over 20 published articles, and has already had a large impact on the field. He is one the very few young applied mathematicians whom I have encountered over the course of my career who have a good feel for what problems are conceptually important for the structure of ecological and evolutionary theory as well as having high level mathematical skills. Michael has contributed in a significant way to our understanding of predator-prey dynamics, disease dynamics and evolution, and the responses of ecological communities to perturbations, and I review those three areas below.

A good deal of Michael's work has dealt with the dynamics of predator-prey (and parasite-host) systems in which there is some type of adaptive change in one or both participants in the interaction. This is not a new topic, and it is one that a number of very talented mathematical biologists had explored. Nevertheless, Michael has uncovered a number of important new results that have surprised me. Michael's 2010 American Naturalist paper (co-authored with his Ph.D. supervisor, Stephen Ellner) examined how insight into rapid evolution could be gained by examining the hypothetical limiting case of very rapid evolution. Here, techniques of time scale separation can be used to reduce the (usually) three dimensional dynamic systems involved in predator-prey interactions with one evolving species. This enables the system to be conceived of as occupying a multi-part critical manifold. Either predator or prey evolution can lead to population dynamics that differs in characteristic ways from those of systems without adaptive change by either species. This approach greatly extended and generalized some more limited results I had published in the 1990s, and that were confirmed in an experimental system by a group at Cornell in the early 2000s. The techniques used in the 2010 paper were applied in Michael's 2011 paper in Ecology Letters, and are also applied in several of his later articles and manuscripts. These have involved analysis of systems in which both predators and prey evolve in response to each other. Steve Ellner and earlier students of his had shown that anti-synchronized cycles, which had been observed experimentally, were due to the evolutionary change of defenses in the prey. Michael showed (in work with Joshua Weitz) that addition of predator evolution allows a range of different eco-evolutionary cycles, and he uncovered suggestive evidence for these in several older empirical studies. Michael has had several more recent papers that expand on this and provide a very general understanding of how the form of predator-prey cycles (primarily the phase lag) depend the amount of genetic variation in each species. His 2018 Ecological Monographs article is a unifying treatment of the various roles that genetic variation have on the dynamics of predator-prey evolution. This unites of number of his previous articles. The work is unique in that recent experimental work (by Becks, Hiltunen and others) has uncovered examples of all of the basic types of nonequilibrium dynamics that he has identified.

Michael's other area of research that predates our joint work involves disease dynamics and evolution; this work began during his postdoctoral position with Joshua Weitz at Georgia Tech. In addition to purely theoretical work (J. Mathematical Biology and J. Theoretical Biology articles), he has carried out work on the use of time series to distinguish the roles of different modes of transmission in generating those dynamics (2013 American Naturalist). He has examined the dynamics of previously unexplored types of systems (bacterium-virus-virophage), and has been involved in analyzing observed patterns of disease prevalence in empirical systems. He is co-PI on a grant with Meghan Duffy at the University of Michigan, combining theory and empirical work on population dynamics in multi-host, multi-parasite systems in lakes.

While it has had a long history, the quest to understand the impacts of indirect pathways of interaction in ecological communities still has many open questions. My first joint project with Michael began as an exploration of the dynamics of a simple model with a long history; two consumer species eating two resources. The question was how the consumers interacted via resource depletion. The aspect we examined, which had not yet been explored, was the potential presence of asymmetric competition between the resources. This had been ignored because of the complexity it caused in the analysis rather than the belief that it was uncommon. Almost all previous empirical studies of competition between species have revealed significant asymmetry. The analysis (mainly carried out by Michael) of our model with asymmetric resource competition revealed a wide range of conditions where consumers of those resources interacted as mutualists or contramensalists. It also revealed a variety of unexpected effects; adding a competitor could cause population cycles even in a model with strictly linear per capita growth-rate functions, for which stability of equilibria was usually assumed. Mortality of a consumer could increase its own density, and this could be true of both of the consumer species in the system. These findings led to a reexamination of how interactions were defined and measured. This work appeared in Ecological Monographs in 2015. It got Michael started on a second article with a deeper analysis of conditions allowing species to increase in equilibrium or mean population size with greater mortality. This work has a variety of very important implications for applied areas; both interpreting the responses of population sizes to deteriorating conditions and to altered harvesting regimes. The counter-intuitive increase is a phenomenon (the 'hydra effect') that I had worked on for more than a decade, but Michael was able to deduce a much more general set of conditions under which it occurs in stable systems. He also explored what the presence of a hydra effect in one species implied for system dynamics when a predator of the hydra-effect species was introduced. This scenario leads to highly unusual changes in the relative abundances of different trophic levels. This idea was expanded and generalized the 2016 Ecology paper. Another implication of our earlier Monographs paper was that species whose interaction was not competitive were predicted to show the standard evolutionary response of divergent character displacement, implying that (contrary to standard thinking) competition was not required for ecological character displacement. An exploration of the evolutionary responses of consumers of competing resources was the third paper in the series, one that appeared at the end of 2016 in Evolution.

Michael has also collaborated with several other biologists dealing with questions regarding the relative number of species in larger biological communities—the study of productivity-diversity relationships (with Pu and Jiang), and the network structure paper by Jover et al.

Michael Cortez' published work includes a paper in PNAS, several in the top impact journals in Ecology (Ecology, Ecological Monographs, Ecology Letters), the top journals in mathematical biology, and the journal of the Society for the Study of Evolution. It is quite a wide range of research outlets, and includes an exceptionally wide range of topics for someone at such an early career stage. One of the impressive things about this body of work is that it was being produced while Michael was starting a job as an assistant professor in a mathematics department that had heavy teaching loads, and while he was carrying on several other collaborative projects (and starting a family) at the same time.

I expect that Michael Cortez will end up having at least as much impact in the areas of theoretical ecology and evolutionary theory as Stephen Ellner, his Ph.D. advisor, which is to say, a great deal of impact. Both his work on disease dynamics and hydra effects have a wide range of implications for applied work. His ability to work collaboratively with a wide range of people is also indicative of his potential for a wide range of future discoveries.

I have heard Michael give at least five or six talks on his research; three of these were at UofT, and all have been excellent—well organized, exceptionally clear, and designed with the audience in mind. He has a good speaking style and I am sure he is a very highly rated and effective teacher. Michael has broad research interests, a strong background in both mathematics and biology, and has had an amazingly diverse set of both older and younger collaborators for someone at his career stage.

I officially retired from the University of Toronto shortly before Michael Cortez and I started our joint work, and I had not originally intended to stay active in research. The project with Michael was too interesting for me to pass up, and I am very happy to have done it, even though it expanded much more than what I originally planned. I renewed my grant last year in large part in order to continue the lines of work I began with him. I think that Michael has and will continue to have major influences on the development of out understanding of the dynamics and evolution of ecological systems.

Sincerely,

Peter A. Abrams, F.R.S.C.
Professor Emeritus of Ecology & Evolutionary Biology