Personal, Background, and Future Goals Statement

The most embarrassing moment of my science career (so far) came early. It was August 2015, and I had just flown to Columbus, Ohio to present the results of my summer REU at the Young Mathematicians Conference. Despite feeling naïve, small, and utterly alone, I still looked forward to the poster session. Everyone would be wowed by my flip-book bifurcation diagrams, which showed a changing mathematical system as the reader thumbed through the pages. I wore my new dress and fancy shoes, ready for my presentation. Except, I wasn't. This being my first conference, my dad had told me how he made posters back in medical school: a good old-fashioned printer, poster board, and glue. I didn't even give it a second thought, so focused was I on the math and the flip-book, and on *what exactly did business casual mean, anyway?* Imagine my shock when I arrived, took in everyone's tidy, printed posters, and realized that mine looked like grade-school art project. I rushed to the bathroom, sobbing, and called my dad (he was mortified). My roommate soon found me, wiped away my tears, and psyched me up to return.

That day, I had to swallow my fears and explain advanced math to "real" scientists, all while feeling like everyone saw me as *that hick girl from rural Virginia*. But I did it. And with some time and perspective, I see how that poster session shaped me as a scientist. Embarrassment and impostor syndrome are strong psychological barriers; if my love of science could overcome something that powerful, then perhaps I had a future in academics. When research setbacks or a global pandemic throw me off balance, I draw on the resilience I forged in that Ohio conference room. I also learned the importance of mentorship and empathy in shaping young scientists' experiences. I will never forget the terror of being so underprepared, so now I teach students not just how to troubleshoot code, but how to navigate the unfamiliar situations and institutions that are an important part of our lives as scientists.

Intellectual Merit: That summer REU was my first stab at being a scientist. My project, overseen by William & Mary (W&M) professors Leah Shaw and Junping Shi, focused on dwindling oyster reefs in the Chesapeake Bay, whose presence is critical for ecosystem health. Mathematically, I was interested in a simple system of two reefs, which were (a) limited by the Allee effect (in which populations that are too small can't persist) and (b) dispersing offspring between reefs (without any being lost along the way). The Allee threshold arises because oysters are filter feeders; a reef must be of a certain height to rise above the bay bed, or else the oysters choke on the silt and die. I modeled the reef interactions using two logistic growth equations coupled through dispersal and modified to include the Allee threshold; parameter values were informed by environmental variables such as water siltiness and turbidity. I used nullclines and nondimensionalization to analyze qualitative properties, proved the non-existence of limit cycles using Lyapunov functions, and created bifurcation and basin of attraction diagrams in MATLAB. Three distinct possible states emerged: (1) both reefs persist, (2) one persists while the other falls to a very low population, and (3) both die. This last finding was most peculiar; with no deaths or loss during dispersal, reef failure was unexpected. My finding was mathematically novel for such a system and will help engineers avoid placing new reefs where environmental factors compel reef failure. I presented this undergraduate research at three conferences, including the Joint Mathematics Meetings (the largest US mathematics conference) in 2016, and wrote my results as my senior thesis in 2017.

After graduating from W&M, I spent two years as a computer programmer for IBM in Washington, D.C. where I developed automated tools to test APIs, crafted pharmaceutical web interfaces, and created a data management system for drug reports at the FDA to more quickly access and review new drug reports. Although my programming skills improved drastically over those two years, I missed the rigors and relationships formed through academic research. Instead of helping others manage their data, I wanted to manage and analyze my own data, study my own systems, and ask my own questions. I wanted to pursue research using my mathematics and programming skills, but at first, I had no idea where to start. As a math major, I was told, "the world is your oyster", but how then was I to sift through the hundreds of options available? Instead of asking myself *What do I want <u>to do</u> with my life?* I asked: *What do I want <u>to be doing</u>? What part of mathematics do I most enjoy exploring?* My answer of dynamical systems and Bayesian statistics eventually led me to Dr. Jim Clark's lab at Duke University.

I immediately gravitated towards the Clark lab's investigations of ecological systems under climate change; their rigorous statistical and computational methods melded nicely with my undergraduate mathematical research. My first foray into graduate-level statistical ecology was helping Dr. Clark to update his generalized joint attribute model (GJAM)[1]. GJAM uses static data to study species distributions across a landscape, but static analyses only capture a snapshot of dynamics that change drastically over time. I was eager to use Dr. Clark's updated, dynamic version of GJAM (GJAMtime)[2] to incorporate the temporal states and species interactions of time-series datasets and provide more accurate analyses of rapidly changing ecosystems. I applied GJAMtime to both simulated and real data (the latter a long-term ecological dataset, detailed in the next section), testing the model's code and outputs against real-world systems knowledge. In November 2019, I wrote a GJAMtime tutorial (available on GitHub) for a workshop on dynamic species distribution models (SDMs) hosted by the French National Research Institute for Agriculture, Food and Environment in Grenoble, France. Over two days, I discussed SDM theory with groups of French, Italian, and German scientists and taught them how to use GJAMtime on their own datasets. Building on conversations from these working groups, I co-authored a paper with Dr. Clark and a fellow lab member, detailing the statistical framework of GJAMtime[2]. We applied GJAMtime to experimental lakes data and the annual Breeding Bird Survey, demonstrating that apparent non-linear responses to the environment can in fact be induced by species interactions. We published our significant findings in PNAS and, along with acceptance into such a widely read journal, our future workshops and tutorials will help spread awareness of such a useful community modeling tool.

The best way to showcase a model's general applications is to use it in analysis of disparate ecological systems. For my first application of GJAMtime, I chose the savanna herbivore community of Kruger National Park. Kruger, South Africa's oldest and largest national park, has a wealth of long-term data including annual herbivore censuses, vegetation biomass collection, seasonal rainfall, and geological and fire history maps. When I first delved into the Kruger literature, countless questions occurred to me about such a diverse community: How do savanna herbivore species respond to the more intense and frequent droughts brought on by climate change? How has park management changed the landscape these herbivores experience? Are some antelope ranges in the park restricted by the expansion of more common herbivores (e.g. *Equus quagga, Connochaetes taurinus*)? A few species of antelope (e.g. *Taurotragus oryx, Hippotragus niger*) are rare across Kruger and are a higher conservation priority for park management. Collaborating with researchers in South Africa, Germany, France, and the USA, I analyzed trends in Kruger's ungulate distribution over time. I presented my preliminary results on rare antelope (RA) ranges at the Ecological Society of America's 2020 conference. I found that species interactions do affect RA responses to water sources and that not all RA respond to their environment in the same way. Sable antelope (*H. niger*) often migrated further from rivers than other RA, and grass availability and rainfall volatility strongly impact their intrinsic growth rates. These findings can inform future management, perhaps inviting a narrower focus on the needs of sable separate from the other RA and have inspired me to pursue further work on RA distributions in Kruger (detailed in my research proposal).

After starting my work with Kruger's savanna system, I became interested in the role that surface water availability plays in herbivore dynamics. This summer I joined a World Wildlife Foundation (WWF) funded project under Dr. Jennifer Swenson using remote sensing to identify and track ephemeral watering holes in the Okavango Delta, Botswana. Remote sensing of watering holes presents unique hurdles depending on the time of year. During the wet season, watering holes are full and easier to find, but imagery is often obscured by clouds. In the dry season, watering holes are small or nonexistent, and though imagery is less cloudy it is difficult to distinguish muddy water from bare soil. After trying many techniques to surmount this fundamental obstacle, our latest attempt has been to use the wet-season locations of watering holes to inform the likely dry-season locations, narrowing the extent over which my colleagues' classification algorithms would have to run. Using Google's open-source Earth Engine tool, I augmented existing code written by Dr. Danica Shaffer-Smith to create buffers around wet-season watering holes for use in dry-season classification. I also leveraged my programming expertise to modularize her code for more general use. In the coming months, I will track these watering holes as they fill up and dry out and hope to apply these analyses to watering holes at my study site in Kruger.

Broader Impacts: Mathematics is the language of science, and computer programming the literacy of the 21st century. And yet, American culture is steeped with a "math anxiety", a vicious cycle of aversion inhibiting practice that can severely inhibit students' ability to grow and use math in the future[3]. In my two years as a statistics teaching assistant, I have seen such an aversion to math and coding affect my students' self-esteem. I often listen to my Master's students share their insecurities at being unable to translate a problem posed in class into code. And yet they show me (and themselves) that, given the chance to learn on their own terms, with examples that they are interested in, students can regain their mathematical confidence and grow in their computer science (CS) skills.

I aim to combat this perceived inability before students leave high school. The NSF prioritizes broadening participation in the sciences, and I will further this goal by working with high school students in Durham Public Schools (DPS) to teach them how useful and fun math and coding can be. DPS's diverse student body[4] (44% Black, 31% Hispanic, 18% White) allows me to reach students with a wide range of backgrounds and life stories. I hope to convey to students of any gender that math and coding are not "boy" oriented, but skills that we all can develop. Low math confidence from an early age[5] inhibits (especially minority) female participation in STEM, with only 18% and 43% of degrees being awarded to women in CS and math, respectively, in 2015[6]. I was fortunate to grow up with supportive parents and teachers who eschewed gendered math stereotyping; I want to give this same support to young students.

For this project, I will apply concrete and exciting ecological data to create more relatable, open-source tutorials on introductory programming and statistics. These will build on RShiny modules that I have already made available on RPubs and GitHub, which focus on the basics of programming in R and on species distribution modeling. I will apply these modules to conservation topics that will engage students, and work with local DPS teachers to implement my modules in their classrooms. With pre- and post-lesson surveys, I will learn if my methods are making a difference in students' skills and confidence.

<u>Future Goals</u>: My philosophy for choosing a career is identical to my philosophy for choosing a graduate school: *What do I want <u>to be doing</u> with my life after graduation?* I want to conduct research that has impacts beyond academia, and I want to teach others while doing so. To these ends, I joined two professional development programs at Duke—the Certificate of College Teaching (CCT) and Environmental Impacts Fellow (EIF) programs. CCT teaches modern, adaptable pedagogy through lecture and observational components, emphasizing accessibility and equity in the digital classroom. EIF is a competitive leadership program that trains and mentors Duke students who wish to make an impact with their careers outside of academia. I attended weekend-long workshops on critical thinking, philosophy, communication, and mentorship, as well as alumni panels on environmental career paths. My mentor, Dr. Evan Mercer, has helped me weigh the merits of industry, government, and NGO careers.

Being awarded the NSF GRFP will allow me to apply my time and skills to my Broader Impacts goal of developing open-source teaching modules for local high schoolers. Additionally, I will take advantage of the GROW (Graduate Research Opportunities Worldwide) program to work with my international collaborators. Since the first day I met the amazing scientists in Grenoble for the GJAMtime workshop, I have been searching for ways to further our collaboration testing species distribution models. The GROW program will provide the funding I need to return to France after travel restrictions have been lifted.

Ultimately, I want to be known not only for what I produce, but for the way in which I produce it. I want to be known for my advances in statistical, dynamic ecology; for future work on climate change in savanna ecosystems; and as an independent thinker who draws on her love of mathematics to answer the pressing ecological questions of her time. I want my tutorials to have an impact beyond my professional circle, teaching others how to approach programming and statistics in a new way. Just as importantly, I want to be known as an empathetic teacher and mentor. I am no longer that young mathematician crying in the bathroom, feeling like I don't belong in science. And yet those experiences are part of my story. If my resilience can inspire others overcome their learning hurdles and battle impostor syndrome, then that is the impact I want to have as a scientist.

[1] JS Clark *et al.* 2017. *Ecol. Monog.* 87. [2] JS Clark, CL Scher, ME Swift 2020. *PNAS* 117. [3] MH Ashcraft & JA Krause 2007. *Psych. Bull. Rev.* 14. [4] Powerschool 2017. Membership by Ethnicity and Gender. *DPSNC.net.* [5] Perez-Felkner *et al.* 2017. *Front. Psychol.* 6. [6] NSF Science and Engineering Indicators 2018. *National Science Board.*