As the plane soared high over the tropical rainforest, my heart rose into my throat. There it finally was, the Panama Canal came into clear view through the dense mist as we descended toward the runway. I never thought that I would travel to another country in my life, nor did I think that I would be a biologist going to the tropics to study bats, of all creatures. My love for nature should have been more obvious to me in my teenage years, as I spent much of my childhood playing with frogs, banana slugs, and insects on the edge of a thousand-year old redwood forest in northern California. Yet somehow at the end of High School, I had no idea what I wanted to do. As neither of my parents went to college, I was expected to get a local blue-collar job. Instead, I took a gamble, and enrolled at a community college in California. This is where my life changed forever. After taking an introductory biology class, I joined a series of field courses to the desert, ocean, mountains, and forests. I immediately fell in love with biology, and for the first time in my life, learning was a joy. Near the end of my time there, I was awarded 'biology student of the year'. This confirmation motivated me, and I began volunteering with wildlife biologists to conduct endangered frog surveys. These surveys were my first experience with hands-on data collection, and it made me want only to dive deeper into research.

Transferring to the University of Montana (UM) was a challenge to myself academically and a deliberate move to seek out first-hand research experience. I was instantly attracted to the research lab of Dr. Douglas Emlen, who studied animal weapons and their evolution. Once I joined his lab, Dr. Emlen introduced me to the diverse world of animal behavior, and taught me how to think like a scientist – making explicit predictions that follow testable hypotheses. After volunteering for one semester, I was awarded an undergraduate research grant from the Honors College to conduct my own research on rhinoceros beetle horn development using modern molecular techniques. Our regular lab meetings and weekly departmental seminars taught me how scientific progress is made and how the scientific method works. These seminars are where I first learned of a mega-diverse tropical forest that is home to a world-class research station. Shortly thereafter, I found out that the Smithsonian Tropical Research Institute (STRI) in Panama has fellowships for young researchers, and I was hooked.

Knowing that I badly wanted to get to STRI, Dr. Emlen helped me draft a cover letter that I could send out to select STRI staff scientists. After much anticipation, Dr. Rachel Page, a STRI bat biologist, offered me a paid fellowship to work with her for a year. Surprisingly, I got the position without really knowing much about bats. However, as fate would have it, Dr. Jesse Barber, a well-known bat biologist from Boise State University, came to our department to give a talk only a few weeks after I accepted the position at STRI. Dr. Barber talked a lot about bats, and their interactions with moth prey, but then he talked about something that fundamentally changed the way that I view the world – noise pollution. His message was one that I had never considered in my life. Human-generated noise (be it by transportation, oil-drilling, or construction) is an environmental pollutant that has negative consequences for organisms and ecosystems. While we humans are habituated to a world consumed by noise, many animals seem to experience strong negative effects. This message resonated with me, and his insights into the bat world stuck. All that was left was to pack for the year-long "trip" to the tropics.

As the plane hit that wet runway, I was a little scared. Not that we would slide out of control, but scared by the fact that I was about to step into a world of research that I knew so little about. When I started at STRI, I came on as a technician. I learned how to capture, handle, and train

wild bats, and how to use microphones to measure bat echolocation. Not long after, I was promoted to lab manager, and started working on my own project. For this project, I used robotic frog models to understand how frog-eating bats use prey-generated cues to hunt for frogs. This project was focused on acoustics of two types. Firstly, bats eavesdrop on frog calls to detect their prey, and then, secondly, they use echolocation to further hone in on the inflating vocal sacs of frogs. The robotic frogs allowed me to test bat preferences to both frog calls and vocal sac cues independently of one another. When I realized how acoustically-driven my work was, the message about noise had returned from weeks prior. I had been pondering Dr. Barber's talk for some time, and this seemed to be the perfect opportunity to test the effects of noise on behavior.

After a quick literature search on the topic, I found that only two papers regarding bats and human-caused noise existed at the time. Once I explained <u>why</u> this project needed to be done, Dr. Page graciously agreed to let me study noise, and then helped me design the experiment. I simply modified our existing setup and added noise, which allowed me to concurrently collect data for this second project without detracting from the first. Then, with an international team of scientists, we analyzed the data and wrote up the experiments together. The first experiment has recently been accepted to the journal *Animal Behaviour*, while the noise experiment was published in *Science* last year. Our most surprising finding from the *Science* paper is that these bats can get around the noise-induced problem of not being able to hear the calls of their prey. While hunting, they did this by increasing effort in their secondary sensory system – echolocation. Thus, a logical next step was to understand the mechanism for how echolocation itself might be affected by noise.

My next project was a laboratory experiment to understand how different noise types can affect bat echolocation. I did this work the following year on a Fulbright grant at the Max Planck Institute for Ornithology in Germany. Along with my mentor, Dr. Holger Goerlitz, I designed an object-discrimination task to measure bat echolocation perception. I trained bats to discriminate and prefer smooth surfaces from rough surfaces via echolocation, and then allowed them to make a choice to one surface or the other in a modified Y-maze. Trials varied in their levels of difficulty, and included blocks of various noise types to experimentally parse out the mechanism of noise disruption to echolocation performance. Varying levels of difficulty allowed me to understand distraction, as a mechanism, since noise should distract bats completing more difficult tasks to a larger degree. Alternatively, I broadcast noise that overlapped in frequency with bat echolocation calls, and noise that did not overlap with their calls. This allowed me to experimentally test noise masking as a mechanism, since only overlapping noise should mask echolocation calls. While, I was eager to get results, this project did not go as smoothly as my previous work in Panama. I struggled to build the experimental setup, which consisted of wiring IR light barriers, setting-up cameras, generating noise playback, and randomization schemes that were all linked via MatLab coding software. Furthermore, my bats in Germany were incredibly tough to train, and each took 2-4 <u>months</u> of training before I could collect any data. While Dr. Goerlitz and I are still preparing this manuscript for publication, it seems that noise can affect individual bats to varying degrees and via different mechanisms.

While laboratory experiments have given me the control to work on detailed animal behavior, their downfall is that they are often far from realistic. To get the best of both worlds, I want to combine laboratory and field experiments. This past summer, I began working with Dr. Jesse

Barber on a large-scale noise playback experiment in the field. We experimentally broadcast whitewater river noise across 20 sites in the Rocky Mountains of Idaho. I organized a team of 8 to deploy large speaker arrays and measure community assemblages. This project was my first experience being in command of such a large team, and also the most logistically challenging project that I have ever been on. While we ran into many technical issues, hard work eventually paid off, and I learned a lot about the fine balance of managing a team. Since the field season has ended, I have joined Dr. Barber's lab as a PhD student, and intend to further my track record of studying both animal behavior and community ecology in noisy situations.

[Intellectual Merit] Research in both Panama and Germany has connected me to an international community of biologists. These experiences have taught me a great deal about biological investigation, culture, and myself – insights that will stick with me for my career and life. Working in Panama showed me how to be a successful scientist. I learned to design and carry out hypothesis-driven experiments, to analyze and interpret results with modern statistics using programming languages (such as R), and I learned how to write scientific manuscripts – which were published in both *Animal Behaviour* and *Science*. Working in Germany, on the other hand, led to much frustration and failure – yet this became a learning experience itself. I came to understand how to have patience and troubleshoot when things go wrong. It was through failure that I ultimately gained a burgeoning confidence in myself. Through these experiences I realized, without a doubt, that I *can* do science, and that I *want* to do science. Additionally, this 'gap' in between undergraduate and graduate work, allowed me to formalize the field I was interested in. After three years of studying animal behavior and sensory systems in noise, I am only more intrigued about what lie around the next corner.

[Broader Impacts] Craters of the Moon National Monument (CMNM) is a park in southern Idaho that is covered by a sea of old lava flows. The park has recently been designated as an International Dark Sky National Monument, and it is likewise a place with limited exposure to noise pollution (although there is not yet an official designation for sound-related things). The CMNM visitor center is conveniently located fewer than five miles from the field site of my proposed research, and within three hours driving time of Boise State University. Furthermore, our lab has a working relationship with CMNM to conduct this research, and my involvement in local public education will go a long way in maintaining that relationship. During my PhD, I will work with educators and rangers at CMNM to put together a series of exhibits and lectures about noise pollution. Each year over 200,000 people come through CMNM to learn about the natural and geologic history of the park. The creation of access to noise pollution education has the capacity to impact many Americans and international travelers as they travel through.

[Future Goals] My proximate goals include continuing my trajectory studying acoustic environments, and I hope to unearth key concepts to the sensory disturbance field. Since it is such a young field, I feel that I have the prime opportunity to insert my influence early on in my career, and then I hope to build on that influence throughout my life's work. This is an appropriate segue into my ultimate goal, which is to become a full-time professor at a research University in the United States. I also look forward to teaching the next generations of students about the discoveries of the comprehensive 'team' of biologists from around the world. Being granted an NSF GRFP will allow me to focus on research, networking, and public outreach in a way that will significantly advance science, our communities, and my career.