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Utah Tick Surveillance an Animated Public Service Announcement

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UTAH TICK SURVEILLANCE
an animated Public Service Announcement

by

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ABSTRACT

As the United States' population grows, we develop more land into housing and recreate farther into wilderness areas, consequentially encountering ticks with increasing frequency. As the climate continues to change, tick population distributions are also changing, influencing our population's exposure to tick-borne diseases. Lyme disease, a tick-borne disease named after Lyme, Connecticut, is one of the fastest growing emerging diseases in North America, and the most prevalent vector-borne infection in the United States. There are two species of tick in North America, *Ixodes scapularis* and *Ixodes pacificus,* known to be carriers of the causative agent of Lyme disease, a spirochete bacteria named *Borrelia burdorferi. Ixodes pacificus* is known to inhabit Utah. The status of Lyme disease transmission in Utah is a subject of ongoing investigation by the Utah Department of Health (UDOH) in collaboration with Utah State University. To better navigate this dynamic situation, an informed public is a great asset to researchers and public health professionals. Towards that end, this capstone project presents an animated Public Service Announcement (PSA) video deigned to better connect public viewers from outside academia and research to the ongoing investigation of Utah's tick population. To better inform the public, the video focuses on the following topics: the nature of ticks as vectors of pathogens; the goals, methodologies, and findings of the original tick survey conducted in Utah; the role of *Borrelia burgdorferi* as the causative agent of Lyme disease and its clinical presentation; guidelines for preventing tick bites, safely removing ticks, recognizing symptoms of tick-borne infections, and seeking additional care and/or information. To emphasize key facets of information like the visual identity of *I. pacificus* and the concepts behind the methodologies of the original tick survey, animation served as the medium of choice.

Acknowledgements

I would like to acknowledge the guidance and counsel of Dr. Scott Bernhardt as a mentor and friend in this project. His experience in conducting epidemiological research in and out of the field was invaluable, and his moral support indispensable towards the completion of this capstone

The trust and patience of Dr. Jennifer Burbank and Dr. Sara Freeman in taking me and the project on as my Departmental Honors Advisors at different times throughout the process were also of great worth.

The encouragement of Dr. Kristine Miller and Amanda Adison at the earliest stages of this project were greatly helpful, as well as their direction throughout the HONR 3900 course.

I would also like to recognize my dear wife Alissa Aguilar for her excellent contribution as narrator in this work, as well as the rest of my family for their many years of loving critique and development of my artistic skills.

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Background

Lyme disease is an infection of the bacterium *Borrelia burgdorferi*, and within the United States its primary vectors for transmission to humans are the black-legged tick *Ixodes scapularis* and the western black-legged tick *Ixodes pacificus* (Burgdorfer et al. 1985, Piesman 1989). *I. pacificus* is mainly distributed along the pacific coast of the North American continent, with limited populations reported in the western and southwestern states of the US, including Utah (Eisen et al 2016).

In 2010, an outbreak of potential Lyme disease cases reported in Utah County, Utah prompted a survey of Utah's tick species distribution, seeking to identify locations with *I. pacificus* and the capacity of any of these populations to transmit Lyme disease; limited populations of *I. pacificus* were identified in central and southern Utah, but none collected showed evidence of infection with *B. burgdorferi* (see Figure 1) (Davis et al. 2015).

While this survey was the first such surveillance effort in Utah, national data leading up to it suggests that the number of US counties with populations of *I. scapularis* and *I. pacificus* counted together expanded by 44% in the two decades prior (Eisen et al. 2016). These trends may be accounted for by the expansion of human development into areas with endemic tick populations, as well as the expansion of tick ranges as a result of climate change (Schwartz et al. 2017, Williams et al. 2021). In correlation with these changes, Lyme disease remains a the most prevalent vector-borne disease in the US, and is among the fastest growing diseases in prevalence (Kugeler et al. 2015)

Passive surveillance surveys since the Utah survey (using samples collected and mailed in to testing centers by members of the public) have reported *I. pacificus* in Utah counties beyond the findings of the original Utah survey (see Figure 2) (Nieto et al. 2018).

To better illuminate any ongoing trends in the distribution of *I. pacificus* in Utah and any capacity Utah's population of these ticks may have to transmit Lyme disease, the Utah Department of Health is currently reinvestigating the original survey sites recorded by Davis et al. and novel sites based on reports from members of the public. A more in-depth discussion of the methods of this survey are discussed later in this paper (see “Written Analysis”).

The remainder of the work presented in this Capstone project is based on the author’s ongoing participation in the reinvestigation of the Utah survey. Initially intended to be a draft scientific publication of the results-to-date of the survey, the first season of tick collection (approximating 40 person-hours’ worth of collection time) yielded only one tick from the field. We are not yet convinced that the tick populations have decreased below detectable levels since 2013, in part because Utah residents have been contacting the UDOH reporting ticks from sites beyond the scope of the original survey. Our teams have been reviewing our sampling methods to determine when will be the best collecting season (subject to weather) and that our efforts in the field are being conducted with the greatest effectiveness.

Without reliable tick distribution data to analyze for the purpose of this Capstone project, the author decided to instead focus on presenting the ongoing research to the public in an accessible and engaging format as an animated Public Service Announcement.

Lyme disease in Utah represents a gap in our scientific knowledge as researchers and public health officials, in part prompting the creation of this PSA. If the public can be effectively informed without raising undue alarm, everyday citizens can contribute to the ongoing research process as they go about their daily lives. Additionally, establishing and maintaining channels of communication between researchers, public health professionals, and the public helps lay the groundwork for other forms of passive tick surveillance practiced elsewhere in the US (Eisen et al. 2021, Mader et al. 2021, Lyons et al 2022).

PSA video link

https://bit.ly/360swha

WRITTEN ANALYSIS

The following analysis addresses the research and creative process behind the production of my Utah Tick Surveillance Public Service Announcement (PSA). Approaching this project, my goal was to create an informative resource for the public of Utah that could empower individuals with information that they can apply in their daily lives while describing the ongoing research at work in Utah and elsewhere. Throughout writing and animating the video, a dynamic of focusing on a particular aspect of information in one form of media and allowing elaboration in another form of media emerged. The written narration was better suited for explicitly stating some facts and public health recommendations, while animation could elaborate on the same information and summarize other ideas wordlessly. Thus, this PSA represents an exercise in research, communication, and artistry that serves to engage and inform the public.

Each major segment of the PSA script (set apart in italics) will be discussed relative to the scientific research and/or public health recommendation it communicates, as well as the animation used in conjunction with the segment.

> *Have you ever gone hiking or played outside and found a tiny, eight-legged bug on you? Maybe you noticed one on your pets? If it looked anything like this, it might have been a tick. In this video, we are going to explain what ticks are in Utah, what we're learning about them, and how to protect yourself from them.*

This segment serves primarily as an introduction to the information to follow. The opening sequence begins as a wide shot based upon the likeness of the Sheeprock mountains, located south of Tooele, UT, where most of the original Western Black-Legged Ticks (*I. pacificus*) collected in the 2015 survey were discovered (Davis et al 2015). The tick brought into focus is a depiction of an individual female *I. pacificus* (CDC 2021). The sequence is intended to call the attention of the viewer, establish the subject of discussion, and outline the structure of the presentation to follow, using the images of the state of Utah, another tick, and the outline of a human being to simultaneously illustrate the interdependence of environment, host, and vector in disease transmission.

> *Ticks are parasitic, hematophagic arachnids—that means they are closely related to spiders and need to eat the blood of other creatures to survive. When they do bite another creature to feed, they can transmit dangerous diseases.*

To penetrate the skin of humans and other animals, ticks use an alternating motion between three mouthparts. Two barbed chelicerae, one each on both sides of a central hypostome, pull the tick forward and into the dermis of the host in a "ratcheting" motion that securely fixes the tick for a blood meal that may last for days if allowed to continue (Richter et al. 2013, Madder et al. 2022). To introduce ticks via their basic anatomy and feeding behavior, I chose to emphasize the parts rather than the process of tick feeding. In this way, I felt most confident that viewers could grasp the scale and appearance of a tick on human skin, and also be better able to tell in the future if they have inadvertently left pieces of the tick in their skin while removing it.

To introduce the ability of ticks to transmit dangerous diseases, I used the relatively familiar image of human red blood cells, being careful to emphasize their stereotypical biconcave disc shape, before showing three *B. burgdorferi* bacterium quickly weave their way between the cells (Medline 2022). I reused this sequence with some minor changes later in the video to reinforce the concept of how transmission occurs and elaborate on the microbial identity of *B. burgdorferi,* as discussed later.

In Utah, there are several species of tick. Each can transmit diseases to humans when they have enough time to feed, so it is important to know where they are and what diseases they may carry.

This segment again presented a question of balancing relevant information with time constraints. There are indeed several species of ticks in Utah, including *I. pacificus*, the Rocky Mountain Wood Tick (*Dermacentor andersoni*), and the Brown Dog Tick (*Rhipicephalus sanguineus*) among others, and each can transmit a variety of bacterial and viral pathogens (Davis et al. 2015). However, for the sake of streamlining the narrative of the PSA, I kept the focus on *I. pacificus* and Lyme disease, and enveloped instruction for addressing other possible infection individuals may contract with direction provided at the end of the video: if people experience any non-specific symptoms of infection like fever, chills, aches, pains, and/or a rash after a tick bite, they should seek medical counsel regardless of what species of tick they encountered (CDC 2021).

Additionally, this allowed more time to illustrate how tick morphology changes as they engorge with a blood meal. If individuals can better distinguish between a tick that has only recently attached versus a tick that has been able to feed long enough to engorge, they can provide valuable information to their healthcare provider. Health experts across several disciplines advise that three criteria be met before administering immediate treatment against a suspected infection with *B. burgdorferi*: first, the tick has been attached for 36 hours or more (easier to estimate by knowing how ticks engorge over time); second, Lyme disease is endemic to the area where the bite occurred; third, the tick is identified as a member of the *Ixodes* genus (Lantos et al. 2021).

One of the ways we study this in Utah is through active surveying. From 2011-2013, researchers from Utah State University surveyed 157 sites in Utah with a history of ticks. They found several different species, including the Western Black-Legged tick, which can be a carrier of Lyme disease.

The sequence showing the actual "tick drag" is based upon first-hand experience. Since 2021, I have been volunteering with Scott Bernhardt's lab at USU in coordination the UDOH to survey ticks using a method employed across the country: a white sheet of flannel is secured to a bar of PVC pipe so that it can be slowly dragged behind the surveyor from a looped piece of rope. Periodically, the surveyor must examine the sheet to see if any ticks have dropped onto it. White flannel is used simply because ticks readily appear against the stark background, not for any attraction ticks have to the color of the material intrinsically. Any ticks we do find are immediately stored in 70% ethanol for preservation, identification, and testing for infection with *B. burgdorferi*.

While my involvement with USU and the UDOH's efforts to survey Utah ticks began in 2021, all our efforts have been in follow up to a statewide survey conducted from 2011 to 2013 (published in 2015). This original survey was in turn prompted by a reported outbreak of Lyme disease in Lehi, UT in 2010, involving 36 individuals. Even after an investigation by public health professionals revealed that the afflicted cases had histories of travel outside of Utah, and therefore did not present sufficient evidence of Lyme disease transmission within the state, public interest prompted additional research. The original survey sites were selected based on interviews with land users from the respective areas, which I animated appearing on a map of Utah as black dots (Davis et al. 2015). While *I. pacificus* was only found in the areas I marked with a highlighted tick icon, they were reported to have a history in some of the other sites surveyed.

Lyme disease often begins as a distinctive "bull's eye" rash, before progressing into fever, chills, joint pain, and other more serious symptoms if not diagnosed and treated early. Lyme disease is caused by bacteria called Borrelia burgdorferi.

In my research for visual references, I learned that "the bull's eye rash" or "erythema migrans" can vary widely from person to person, especially in relation to the skin tone of the individual affected. Most of the images available on the CDC website depicted fairer complexions, as does a Google image search for erythema migrans. To better capture the range of presentation, I included erythema migrans inflammation on the calf of both a Caucasian and person of color.

Among the "more serious symptoms" mentioned in passing, patients without antibiotic treatment may progress to suffer from heart inflammation and arrythmia, neurological deficits, and facial palsy. Even after treatment, individuals may present with a chronic inflammatory condition, continuing to suffer from debilitating fatigue and arthritis. This presentation constitutes "Post-Treatment Lyme Disease Syndrome" or "PTLDS" (CDC 2021).

I chose not to depict visual representations of these more progressed symptoms due in part to their more visceral nature, trying to avoid ambiguity within the time constraints of the PSA. Additionally, the intention of the video is to inform members of the public about key signs and symptoms to watch for early on when at risk of infection so they can better seek medical attention as appropriate—not to replace diagnosis by medical professionals.

To guide the depiction of *B. burgdorferi*, I used images from online medical encyclopedias, but I found it most rewarding to learn and depict the characteristic movement of *B. burgdorferi* as spirochete bacteria. The bacteria incorporate sugars from their tick hosts directly into their own cell walls, creating a bacterial cell wall uniquely adapted to the torsional strains they induce upon themselves using flagella laid within the cell wall (DeHart et al. 2021). These findings were only published in the past year and help explain why the bacteria can travel so much more rapidly than human cells in living tissue, which in turn may contribute to their persistent evasion of our immune system (Malawista and Chevance, 2008). It was exciting to depict the bacteria alongside red blood cells as not just aimlessly suspended cells among others, but to instead emphasize their capacity for relatively rapid chemotaxis. The animation is more dynamic for this and captures the essence of what makes scientific art fulfilling for me as a student.

We can test ticks for B. burgdorferi using PCR. All the Western Black-Legged Ticks collected in the original survey tested negative for B. burgdorferi.

"Polymerase chain reaction (PCR)", has become much more ubiquitous in public discourse since the COVID-19 pandemic, as a Google search frequency history shows (see Figure 3). In summary, PCR takes advantage of the DNA replication machinery of high-temperature loving bacteria to replicate, or "amplify", DNA samples (Nobel 1993). This process proceeds at an exponential rate, with each single double strand produced capable of becoming templates for two more double strands. Thus, minute amounts of *B. burgdorferi* DNA in *I. pacificus* (or COVID-19 RNA in *Homo sapiens*) can be found and amplified to detectable levels. I have participated in various other DNA extraction and PCR procedures with other organisms (albeit not yet with ticks from this project) and enjoyed the challenge of deciding which aspects of the process to depict literally or conceptually, with greater or less emphasis. For the sake of the PSA, I ultimately decided that showing the destruction of the ticks themselves as part of the DNA extraction process would be the best way to transition into the more conceptual presentation of PCR. Since its development in 1985, genomic research laboratories have implemented PCR as a standard of procedure. As PCR results have come to dominate so much of our daily lives, from vacation bookings to being able to attend in-person lectures on USU’s Logan campus, I am excited to contribute another take on explaining PCR visually to the public.

Starting in 2021 researchers and volunteers have been returning to the same sites and new ones. As we gather and test more ticks, we can better understand how their range is changing with the climate and see if any have picked up B. burgdorferi.

I decided that reusing animation sequences for this segment would be best because there was no new information conceptually, and the prior concepts could be better reinforced in the given time.

In the meantime, what does that mean for staying safe in Utah’s great outdoors? When hiking, avoid walking through tall brush, and stay towards the centers of trails.

For this segment, I chose to depict the opening landscape shot of the video from a different angle to bring the viewers mind back to a more applicable, real-life scale, while still being familiar within the visual style of the animation.

This segment neglects instructions available from the CDC on applying pesticides already in use against mosquitos and other arthropod pests that can be used to prevent tick bites (CDC 2021). However, given that many individuals already use these chemicals outdoors and the time constraints of the video did not allow proper instruction on safely using them, I chose not to include such information in the video.

After you get home from your time outside, check your clothing for ticks. Within two hours of spending time outdoors, do a full-body check for ticks, checking closely in your hair, behind your ears, in your armpits, and behind your knees. Check your pets closely too if they went with you.

For this sequence, I opted to use a neutral-as-possible depiction of a human being, allowing the narration to emphasize the necessity of a full body check. I chose to animate the dog more fully to reengage the audience after the less-dynamic depiction of a human.

Interestingly, vaccines against Lyme disease are available for canines, while the human version of the same was withdrawn from the market following public suspicion of the vaccine causing PTLDS symptoms. These misconceptions were eventually disproven, but new vaccines for humans remain in development, including novel (mRNA) approaches as well as traditional vaccine designs (Oaklander 2021).

If you do find a tick, use a pair of tweezers to remove it. Grasp the tick as close to the skin as possible and pull it out slowly. Afterwards, wash your skin and hands with soap and water.

In sharing this PSA with my mentor and other peers from older generations, this segment prompts the most comments, usually anecdotal accounts of people using other methods to get the tick to remove itself by touching its body with a freshly extinguished match or hot knife blade. In any case, the removal method depicted is in line with current CDC recommendations, presumably because the anecdotal methods may have left more burn injuries than were worth avoiding ticks leaving mouthparts in the skin upon forceable removal.

If you notice a rash around the bite or feel aches and pains with fever and chills after being bitten, talk to your doctor. If you have other questions, reach out to epi@utah.gov

At this point, it felt most appropriate to reinforce the appearance of erythema migrans while explicitly stating the general guidelines for self-monitoring after a suspected tick bite. While the UDOH does not yet have capacity for testing ticks sent in from members of the public, the invitation to contact epi@utah.gov with other questions as a call-to-action serves as an enabling conclusion to the PSA.

Given the opportunity to address the limitations of this PSA with an updated version, my chief concerns would be outlining the visual identity of other Utah ticks to better equip public viewers. Additionally, this video allowed for simple, direct instruction to seek medical counsel after being put at risk by a tick bite but does not elaborate on the complexity of Lyme disease testing and treatment that may frustrate future patients (Adrion et al. 2015).

Despite these limitations, I am confident that this PSA can serve as an effective introduction to the subjects of ticks, tick-borne diseases and prevention, Lyme disease in Utah, and tick surveillance in Utah. In this, it fulfils its designation as a "public service", and with proper publishing in an online format can also measure up as an announcement with a significant audience.

Word count: 3278

Figures

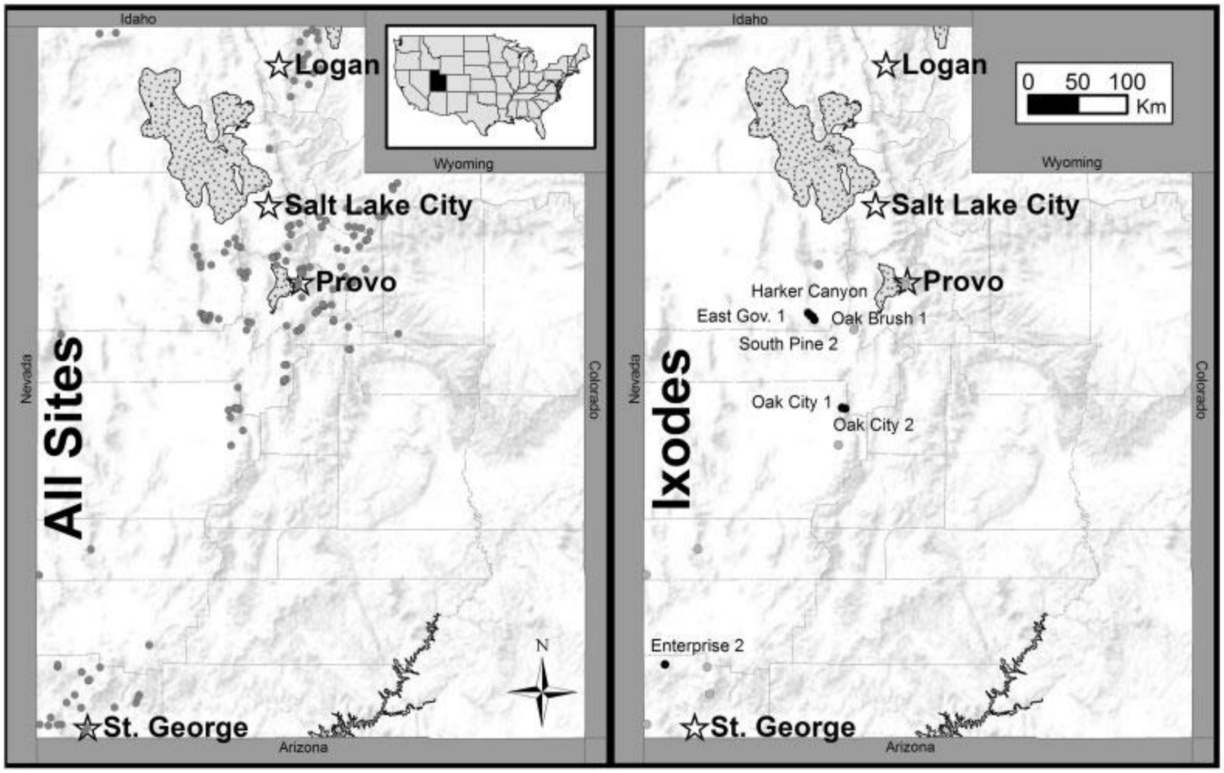

Figure 1: "Distribution of tick sampling locations in Utah. All locations sampled from 2011 to 2013 are on the left map. Current collections (dark circles) and historic records (gray circles) for I. pacificus in Utah are on the right map. Stars indicate major city locations" (Davis et al. 2015).

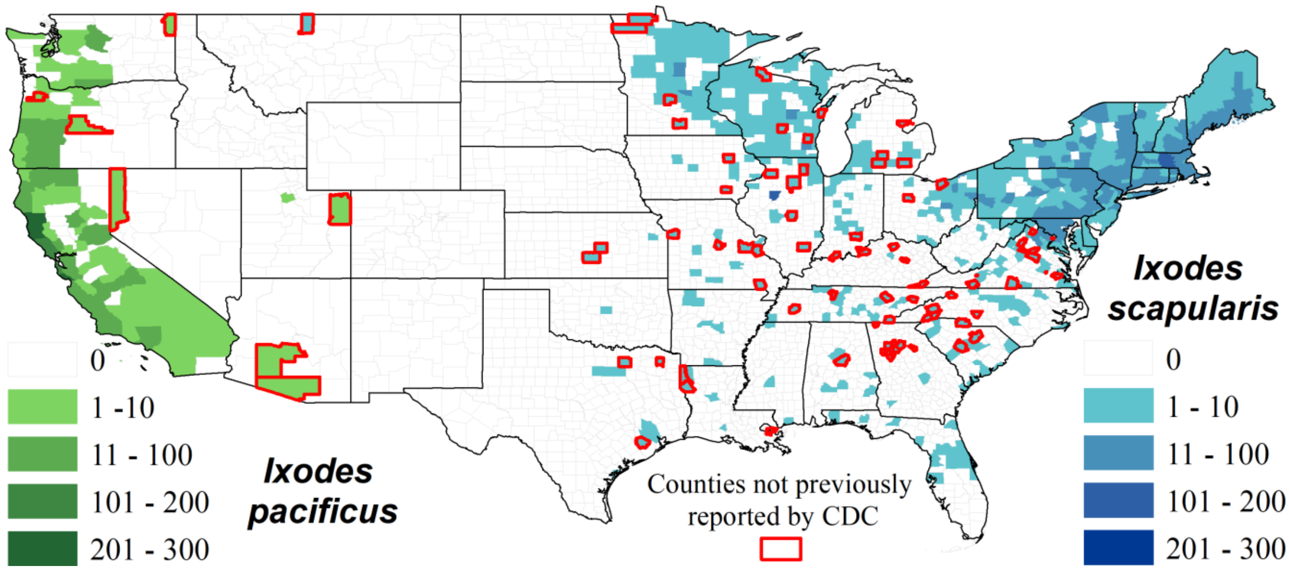

Figure 2: "The county level distribution of I. pacificus and I. scapularis based on location data collected by citizen scientists. Counties outlined in red did not have previous records according to [12], no records include travel history of the submitter" (Nieto et al. 2018).

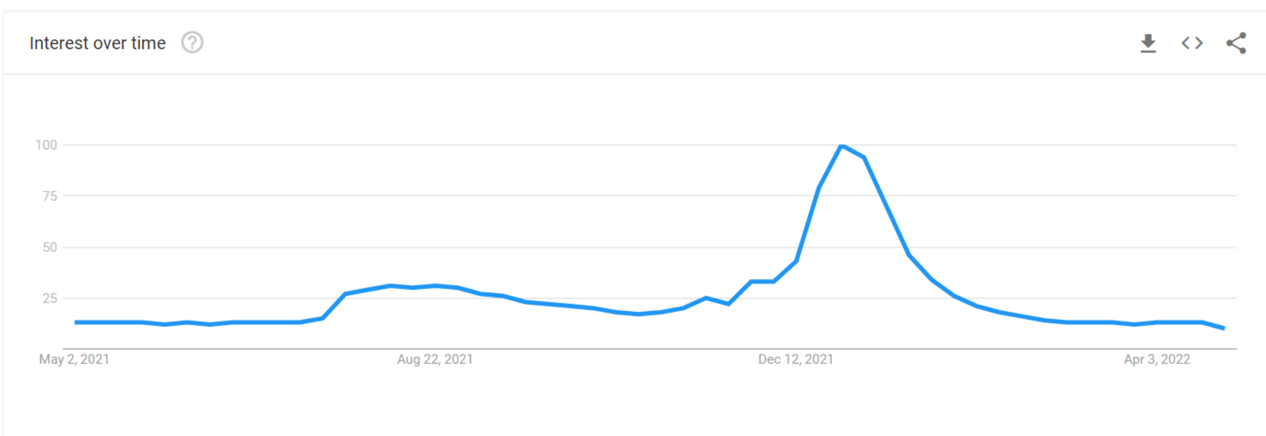

Figure 3: Google search frequency for "PCR"; "Numbers [Trendline] represent search interest relative to the highest point on the chart for the given region and time. A value of 100 is the peak popularity for the term. A value of 50 means that the term is half as popular. A score of 0 means there was not enough data for this term" (source: Google)

Reflection

My experience in undergraduate education has centered around my goal of becoming a physician, my path towards that goal as a biochemistry major, and my role as an illustrator, animator, and cartoonist for the University student newspaper, the Utah Statesman. This capstone project has drawn deeply upon each part my experience so far, incorporating Dr. Scott Bernhardt's mentorship of me as a student and helping me to ultimately produce a final product I am proud to present as a milestone in my education.

USU's program for Biochemistry divides students' time between two overall methods of learning: guided lecture and in-laboratory instruction. For me, each has built upon the other, sometimes in synchronous, starting with a foundation in general physics, biology, and chemistry that progressed into organic (carbon-based) chemistry and then into biochemistry proper. At any given time during these years, the most rewarding moments were when the real-world application of our new knowledge was most clear.

These "ah-ha" moments for me included how glycolysis explains us breathing in oxygen and exhaling CO_2, how specificity and affinity of protein binding to substrates explains how cells send and receive signals, and how and why some drugs have the side-effects they do, among others.

Such moments reminded me that my college education was not transpiring in a vacuum. While working as a Certified Nursing Assistant, I worked with people at all levels of health. As I measured vitals like temperature, blood oxygen level, and breathing rate, the biochemical forces at work behind them played out in my head.

In lecture, I learned how a base-pair substitution in the genome of SARS-CoV-2 would be translated into spike proteins that had greater affinity for the cells in our body. As a COVID-19 contact tracer working with the Utah Department of Health, I worked with one household at a time, and learned firsthand what that greater affinity means in terms of transmission and disease rates.

Working in such medical roles while learning the science behind them cemented the idea in my mind of how important it is to provide accessible information to the public. My capstone project did not originally begin with that motive but instead evolved into it in the face of obstacles and opportunity.

While my major and outside work experience have focused on preparing to be a physician, one activity has not been as directly linked to that overarching goal. As an employee for USU's student paper, the Utah Statesman, I have published artwork every year of my attendance. More recently I have enjoyed drawing my own cartoons, but the greater proportion has been illustrating for the opinion section of the paper. My role has been to provide images that accent, emphasize, clarify, and/or call attention to the arguments of the writers. While my formal education in art is limited, I have learned a great deal about how to understand the opinions of others in one medium, then summarize and elaborate on them in another.

This Honors capstone project represents my best effort to draw upon all these experiences and integrate them into something that is useful and interesting to others, on or off-campus.

I first met my mentor, Dr. Scott Bernhardt, early in the Spring of 2020. Originally, I sought him out for my interest in infectious diseases and epidemiology, and my desire to gain research experience outside of class. These interests have been well-rewarded since then, particularly in his guidance through this project. My experience in Dr. Bernhardt's laboratory expanded my horizons to look beyond the clinical biology of any one human case of disease. From participating in his research, I have been learning how to account for the biology of vectors like ticks with Lyme disease or sand flies with leishmaniasis. The challenges of obtaining and maintaining biological samples to study, as well as conducting research that can be meaningfully applied to the fields they came from, has been at the forefront of my time with him.

Dr. Bernhardt was the one that originally pointed me towards this project with the Utah Department of Health. As my project changed into an animated PSA format, our discussions drew more heavily upon shared experiences as COVID-19 contact tracers. In questions of disease, particularly disease that can spread, working with the public demands not only understanding of scientific fact but also expertise of communication. Without careful navigation, one may lose too much accuracy of information at the expense of making your information approachable to people from a wide range of educational and cultural backgrounds. With contact tracing, we could make the most of direct, one-on-one conversations with individuals, answering their questions in real time. Dr. Bernhardt's experience and expertise has been invaluable in navigating the writing of a PSA that must stand the test of being as accessible to as wide a range of people as possible without losing the substance of the information the video communicates.

Aside from this, he has stood out as a mentor that has always been willing to discuss what I have been learning, point my attention to new directions worthy of pursuit, and to allow me to learn how to discover my own errors for myself. He has spared me from the least valuable mistakes but has still allowed me to learn from my own experience so that I could return to our discussions better equipped to move forward.

He has prepared me to better seek mentors and peers as I progress in my education. Long after I graduate from USU and medical school afterwards (as I hope to), the challenges of being a physician will demand timely coordination of care with teams of people. Simple solutions will require just as much clarity of communication as more complex methods to address the health of individuals and the public we constitute together.

As I watch my video now, my mind traces a path all the way from the broadest levels of public health to the biophysical chemistry of *B. burgdorferi*. I watch, wondering, at how *B. burgdorferi* can incorporate the sugars of tick cells into its own twisted cell wall, leading to is ability to migrate through human tissue after infection and induce the inflamed bulls'-eye rash we know for Lyme disease for so distinctly. I marvel at the interplay between the biology of that bacteria and the biochemical surveillance of both our own immune systems and our modern laboratory testing techniques. At another level, communities grow, the climate changes, and the presentation of Lyme disease changes by entire counties at a time—the surveillance of Lyme disease at a national level raises new and intriguing questions about our future as researchers, educators, healthcare providers, public health workers, and the public we work with.

For all these things, this project has captured the curiosity and fascination that led me to and through Utah State University and its Honors Program as an educational opportunity. I will remember it fondly, and share it proudly, in years to come.

Word count: 1158

Works Cited

Adrion, Emily R., John Aucott, Klaus W. Lemke, and Jonathan P. Weiner. "Health Care Costs, Utilization and Patterns of Care Following Lyme Disease." *PLOS ONE* 10, no. 2 (February 4, 2015): e0116767. https://doi.org/10.1371/journal.pone.0116767.

Burgdorfer W. Lane R. S. Barbour A. G. Gresbrink R. A. Anderson J. R.. 1985. The western black-legged tick, Ixodes pacificus: a vector of Borrelia burgdorferi. Am. J. Trop. Med. Hyg. 34: 925–930.

CDC. "Signs and Symptoms of Lyme Disease | CDC." Centers for Disease Control and Prevention, January 15, 2021. https://www.cdc.gov/lyme/signs_symptoms/index.html.

Davis, Ryan S., Ricardo A. Ramirez, J. Laine Anderson, and Scott A. Bernhardt. "Distribution and Habitat of Ixodes Pacificus (Acari: Ixodidae) and Prevalence of Borrelia Burgdorferi in Utah." *Journal of Medical Entomology* 52, no. 6 (November 2015): 1361–67. https://doi.org/10.1093/jme/tjv124.

DeHart, Tanner G., Mara R. Kushelman, Sherry B. Hildreth, Richard F. Helm, and Brandon L. Jutras. "The Unusual Cell Wall of the Lyme Disease Spirochaete Borrelia Burgdorferi Is Shaped by a Tick Sugar." *Nature Microbiology* 6, no. 12 (December 2021): 1583–92. https://doi.org/10.1038/s41564-021-01003-w.

Eisen, Rebecca J., Lars Eisen, and Charles B. Beard. "County-Scale Distribution of Ixodes Scapularis and Ixodes Pacificus (Acari: Ixodidae) in the Continental United States." *Journal of Medical Entomology* 53, no. 2 (March 2016): 349–86. https://doi.org/10.1093/jme/tjv237.

Eisen, Rebecca J, and Christopher D Paddock. "Tick and Tickborne Pathogen Surveillance as a Public Health Tool in the United States." *Journal of Medical Entomology* 58, no. 4 (July 1, 2021): 1490–1502. https://doi.org/10.1093/jme/tjaa087.

Kugeler, Kiersten J., Grace M. Farley, Joseph D. Forrester, and Paul S. Mead. "Geographic Distribution and Expansion of Human Lyme Disease, United States - Volume 21, Number 8—August 2015 - Emerging Infectious Diseases Journal - CDC." Accessed March 29, 2022. https://doi.org/10.3201/eid2108.141878.

Lantos, Paul M., Jeffrey Rumbaugh, Linda K. Bockenstedt, Yngve T. Falck-Ytter, Maria E. Aguero-Rosenfeld, Paul G. Auwaerter, Kelly Baldwin, et al. "Clinical Practice Guidelines by the Infectious Diseases Society of America, American Academy of Neurology, and American College of Rheumatology: 2020 Guidelines for the Prevention, Diagnosis, and Treatment of Lyme Disease." *Neurology* 96, no. 6 (February 9, 2021): 262–73. https://doi.org/10.1212/WNL.0000000000011151.

"Lyme Disease - Borrelia Burgdorferi Organism: MedlinePlus Medical Encyclopedia Image." Accessed April 9, 2022. https://medlineplus.gov/ency/imagepages/1427.htm.

Lyons, Lee Ann, Nohra Mateus-Pinilla, and Rebecca L. Smith. "Effects of Tick Surveillance Education on Knowledge, Attitudes, and Practices of Local Health Department Employees." *BMC Public Health* 22, no. 1 (December 2022): 215. https://doi.org/10.1186/s12889-022-12667-2.

Mader, Emily M, Claudia Ganser, Annie Geiger, Laura C Harrington, Janet Foley, Rebecca L Smith, Nohra Mateus-Pinilla, Pete D Teel, and Rebecca J Eisen. "A Survey of Tick Surveillance and Control Practices in the United States." *Journal of Medical Entomology* 58, no. 4 (July 1, 2021): 1503–12. https://doi.org/10.1093/jme/tjaa094.

Malawista, Stephen E., and Anne de Boisfleury Chevance. “Clocking the Lyme Spirochete.” *PLoS ONE* 3, no. 2 (February 20, 2008): e1633. https://doi.org/10.1371/journal.pone.0001633.

Nieto, Nathan C., W. Tanner Porter, Julie C. Wachara, Thomas J. Lowrey, Luke Martin, Peter J. Motyka, and Daniel J. Salkeld. “Using Citizen Science to Describe the Prevalence and Distribution of Tick Bite and Exposure to Tick-Borne Diseases in the United States.” Edited by Brian Stevenson. *PLOS ONE* 13, no. 7 (July 12, 2018): e0199644. https://doi.org/10.1371/journal.pone.0199644.

NobelPrize.org. “The Nobel Prize in Chemistry 1993.” Accessed April 19, 2022. https://www.nobelprize.org/prizes/chemistry/1993/press-release/.

Piesman J. 1989. Transmission of Lyme disease spirochetes (Borrelia burgdorferi). Exp. Appl. Acarol. 7: 71–80.

Richter, Dania, Franz-Rainer Matuschka, Andrew Spielman, and L. Mahadevan. “How Ticks Get under Your Skin: Insertion Mechanics of the Feeding Apparatus of Ixodes Ricinus Ticks.” *Proceedings of the Royal Society B: Biological Sciences* 280, no. 1773 (December 22, 2013): 20131758. https://doi.org/10.1098/rspb.2013.1758.

Schwartz, Amy M. “Surveillance for Lyme Disease — United States, 2008–2015.” *MMWR. Surveillance Summaries* 66 (2017). https://doi.org/10.15585/mmwr.ss6622a1.

Williams, Carter, KSL com | Posted- June 2, and 2021 at 6:24 A.m. “Have Utah’s Tick Numbers Ticked up? What the State’s Recent Climate Means for Ticks, Humans, Pets and Wildlife.” Accessed April 5, 2022. https://www.ksl.com/article/50177743/have-utahs-tick-numbers-ticked-up-what-the-states-recent-climate-means-for-ticks-humans-pets-and-wildlife.

Author Bio

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