Perpetua

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Letter from the Editor

Students, faculty, staff, and the University of Alabama in Huntsville community,

It brings me great joy to present to you the latest issue of *Perpetua*. This semester has been one of many trials and new adjustments, but I am incredibly proud of how, not only our editorial staff, but also the entire community surrounding our university has handled this period of great change. I would like to extend a thank you to all of those involved with this issue, including the authors and editorial staff, but also the graduate students, faculty, and many more who contributed their time and thoughts to the publication.

Despite the challenges, I am very pleased that *Perpetua* has been able to continue to be a platform for undergraduate students who wish to have their work published and share their passions with our community and more. As *Perpetua*, founded in 2016, has entered its fourth academic year of this mission, we are pleased to be trusted with presenting these works with excellence. Throughout these years, *Perpetua* has consistently been represented by the symbol of a torch. With our most sincere wishes, we hope that this presentation of undergraduate research will work as a torch to guide curious members of the undergraduate community into the beautiful world of research. We encourage all those who dream, all those who think outside the box, and all those with a natural curiosity to enter this world with us, and not let your voices and ideas be hidden.

Sincerely,

Ashleigh Oliver
Editor-in-Chief
Perpetua

Special Thanks

Perpetua is a collaborative effort and publication would be impossible without the support of numerous individuals and organizations across UAH and throughout the greater Huntsville research and outreach community. We offer special thanks to all who have contributed their time, expertise, financial support, and hard work to Perpetua. A few of our biggest contributors are recognized below.

First and foremost, we would like to thank the undergraduate student researchers for entrusting us with the privilege and the responsibility of promoting their work. We thank the various faculty and staff who serve as sponsors to undergraduate research and to the Summer Community of Scholars for providing resources and opportunities and who likewise support and promote undergraduate research.

We thank the Office of Student Life for providing ample opportunities to promote Perpetua and its purpose. We thank the Office of Academic Affairs for enabling us to reach as many members of the UAH community as possible Next, we would like to extend our thanks to our faculty advisors: Mr. David Cook, Dr. Yu Lei, and Dr. Hamsa Mahafza, who have consistently provided exceptional insight and guidance to our editorial staff since our inception.

Finally, we thank every UAH graduate student and faculty member who served as a reviewer for one of the manuscripts featured in this issue. Without such individuals volunteering their time and expertise, Perpetua would not be able to provide our services to the UAH community.

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Outlining the Definitional History of Technical Writing Through Contemporary Scholarly Voices

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Abstract – The history of technical writing is well established, but the history of its definition is not. *Technical writing* as practiced today is a far narrower category than what was considered technical writing mere decades ago. One cannot easily trace this organic focusing of definition back directly to individual thinkers and scholars. Despite this, individualized historical arguments on technical writing remain useful in demonstrating a pattern of evolving academic thought on the subject. Using selected accounts from conference presentations and scholarly articles published from the 1960s to the 1980s, this paper argues that, over time, technical writing's definition narrowed from covering all texts on technical topics to defining a specific rhetorical category characterized by clarity, flexibility, and- a proximity to the technical fields. Contemporary articles demonstrate that this more exact definition brought with it , a new academic appreciation for technical writing as a legitimate and freestanding field of writing.

Technical Writing, as a discipline of writing, is both deeply old and relatively new. Writers have performed the essential practice since ancient history, but the discipline only received its name around the time of the World Wars, when the form of writing became useful for its clear, succinct style and its practicality in the science, technology, engineering, mathematics (STEM), and professional fields. Just as it has been connected to these fields since its named birth from the technology of the defense industry, Technical Writing has continued to follow the spread and growth of new advancements from the STEM disciplines. Such growth keeps it relevant to the academic world, generally among English and Communications scholars, as universities offer students courses, concentrations, and even majors in technical writing.

Despite Technical Writing's modern relevance, research on its history is surprisingly limited. *History* here does not refer to its *literal* history, as it is easy to follow the progression of technical writing from ancient history into the modern era. The literal chronological progression is only half of Technical Writing's history. Older technical writing work was generally never referred to as such in its own day and age, even pieces modern readers would identify as obvious examples of the form. In a similar vein, *technical writing* from its early named era often falls outside the styles and forms modern writers would classify as technical. The contrast here reveals the weakest area of technical writing study: its conceptual history. Over the period ranging from the World Wars, when the term *technical writing* first came into use, to the present day, Technical Writing evolved, from a synonym for written data, into a unique discipline, distinct among writing forms both by its defining characteristics and its proximity to technology. This evolution, produced by a cultural shift in the understanding of the discipline, cannot be attributed to specific academics and English theoreticians; the ambiguity may explain why research on the subject is limited, as the lack of historical figureheads makes it challenging to pinpoint distinct events that hypothetically formulated the modern concept of technical writing. These limitations restrict us from producing a strict timeline, but we may instead establish the framework of one. By observing a variety of contemporary scholarly opinions and discussions of technical writing, we can create a reasonably accurate picture of how academic thought came to define the discipline of Technical Writing.

This paper intends to create such a picture of technical writing's history to begin to fill the gaps in the established understanding of its historical progression. To demonstrate the progression, this paper's discussion is comprised of three main sections that examine both the historical academic discussion on technical writing and the current state of the discipline this discussion produced. First, I consider and expound on how technical writing is defined in the present based on current scholarly thought. This section defines the endpoint that academic study eventually reached, allowing the paper to track the path of developing thought over time as it made its way there. Next I look briefly at the literal history of technical writing from early civilization to the postwar era. Reiterating this information, though it has been researched and presented before by others, is critical here as grounding context, establishing the foundation of the discipline from which academic discussion sprung. Finally, I examine several speeches, presentations, and papers written by academics and professionals, in both the STEM and writing fields, from the 1950s onward. Presenting these historical views in a roughly chronological order, I analyze their ideas for advancing technical writing, extrapolating from them to create a picture of how the broader community progressed technical writing from a subdiscipline of engineering to a wholly distinct area of writing.

Technical writing as a study, discipline, or even concept cannot be meaningfully discussed until we first develop a definition for it. The word *technical* does it no favors, as it suggests that technical writing exists only as a utilitarian extension of the STEM fields. Many modern academic courses on the subject, such as those provided by the University of Alabama in Huntsville, expand the subject's title to suggest broader applications: Technical and Professional Writing. Well-intentioned retitling may clear away the misunderstanding that technical writing is exclusive to STEM, but at best it only expands the field's visible job prospects while simultaneously burdening it with an unnecessarily cumbersome new title that pulls more focus away from "writing". Academics have generally left behind their past relegation of technical writing to a secondary tool of engineers as their study of the field advanced, and therefore this paper too will reject the literalization of "technical writing" into "writing on technical topics." In place of defining technical writing by its topics, then, we must instead define it by the style and rhetorical techniques to which it adheres.

I do not draw such a definition from the ether but, rather, draw it from the historical progression of academic discussion on technical writing. Couture frames this way of defining technical writing (and writing of a similar nature) as "rhetorical" rather than "technical": "Often, we confuse rhetorical categories with technical categories, a problem particularly troublesome in studies of professional discourse. Engineering writing, for instance, can stand as a rhetorical category but not as a technical category" (Couture 10). When the concept is restructured, as Couture does, into a topic of rhetoric, it becomes clear why defining technical writing by its subject matter is too reductive to be meaningful. The range of types and topics of work a technical writer could hypothetically perform, even when narrowed down to the "technical" STEM fields, is too broad to be useful as a definition of any significance. Similarly, individuals in these fields may produce material that, despite falling under the literal categories of *technical* and *writing*, would not be considered "technical writing." For example, one can easily reject transcription of raw data, though it is technical, from the title of technical writing, demonstrating the inaccuracy of framing technical writing as a technical category. Technical Writing's proximity to technology is worth an addendum to its definition, but it does not itself make a useful definition. If technical writing cannot be strictly defined by its subject, then, we must instead define it by its style.

When considering the styles that distinguish the unique field of Technical Writing, we may again return to Couture's analysis of the topic. Couture looks to categorize technical writing in the context of its professional production in the workplace (Couture 26). Her decision to maintain this connection in her definition is fair as, though we reject defining technical writing on material terms, most technical writers produce their work in a professional environment, and thus they write stylistically based on that environment's concerns. The foremost of these concerns, as identified by Couture, are readability and accommodation; Couture's chosen terms here sound perhaps too interchangeable to effectively describe two distinct topics, though, so I will instead refer to them respectively as clarity and flexibility in writing. Clarity in technical writing is the writer's use of language, style, and format to effectively deliver information and instruction to the reader. The standards that govern what is classified as "effective" vary, but formal guidelines issued by technical writing-related organizations put a heavy focus on prose. The American Institutes for Research, in their guidelines for document design, advise foremost that writers use active voice and direct address and avoid nominalizations in favor of action verbs (28). These style guidelines demand a writing style that is simple and direct, distinguishing technical writing within its fields of application from the more passive and frequently dense style of more strictly scientific writing.

The plurality of "fields" regarding technical writing's applications also characterizes its second major concern, flexibility. Couture's definition of flexibility calls it "effacing one's own identity to best accommodate the professional needs of a variety of audiences" (28-29). This variety in professional needs returns to the previously discussed reason why technical writing cannot be usefully defined by its subject matter, as its very nature is to be applicable to many professional contexts. Too many professional fields call on technical writing to produce too many kinds of documents for the discipline to be easily categorized; while any individual piece of writing, and many fields of writing as well, has a defined audience and purpose, the flexibility of technical writing defines it on its breadth of both. Technical writing's range of potential purpose ties flexibility back to clarity, as truly effective technical writing understands and practices the minute but critical requirements of style that distinguish each of its myriad applications.

Thus, from combining these two principles, clarity and flexibility, while still acknowledging its relation to the technical fields, do we arrive at a definition of technical writing fit for practical use. Technical writing is instructing or accommodating writing, composed with a focus on audience accessibility and flexibility of format, that generally accompanies and augments technology.

For clarity's sake I have preceded historical analysis of technical here with a fully developed definition of the topic. Ideally the foundation of understanding established here will act as a basis by which past attitudes towards technical writing may be compared to each other as they developed over time. I must emphasize though that, in the earlier days of technical writing, as a named domain of work, contemporaries still defined the discipline largely in the manner rejected by modern definitions, classifying it as all writing related to STEM. Many devoted academics took many years of research and argument to instead establish technical writing as a rhetorical category. So then, when examining older discussions on technical writing, a reader must consider the source carefully to determine in which way the author has elected to deploy the phrase. Through this kind of informed analysis, patterns emerge from historical accounts that underpin their overtly spoken shift in attitude toward technical writing; as contemporary academics began to consider technical writing's style over this subject, they recognized better its place as a distinct and valid discipline of the humanities.

Technical communication (a broad category that shares the rhetorical goals of technical writing but encompasses it alongside other disciplines which do not necessarily involve writing in the strictest sense of the word) has had a long and storied history, one which dates back to astrological observations transcribed by ancient civilizations like the Babylonians and Aztecs. O'Hara notes Muhammad ibn Musa al-Khowarizmi, a Persian scholar who lived in the 12th century, as one of the earliest great technical communicators; Al-Khowarizmi, best known as the inventor of algebra, published his many findings in science and mathematics in instructive manuscripts in what could be considered foundational examples of technical writing. Looking past the technical writing of ancient history, the rapid advancements of the Renaissance from the 14th to 17th centuries set the stage for great progress for technical communication, particularly writing. Scientific study, technology, philosophy, and academia blossomed, watered by the purse of rich patrons, and the ability to capture the wealth of new knowledge in writing spread widely as Gutenberg's movable type printing press found its way to new publishers throughout the western world (O'Hara 1). Eisner picks out from this period Geoffrey Chaucer as a key technical writer of the era. Though better known for his magnus opus *The Canterbury Tales* and his many smaller poetic works, the 14th century English author also produced *Treatise of the Astrolabe*, a work explaining to his son Lewis the usage of an astrolabe (an antiquated tool for astronomical measurements) in what has been labeled "the oldest work written in English upon an elaborate scientific instrument" (Eisner 179). Chaucer's early piece laid a foundation for the introduction of technical writing principles into the English-speaking world. As these western nations continued into the Industrial Age, technical communication continued with them, fed by the continuous development of new technology and often housed by the rapidly growing number of scientific and academic journals published to document the era's advancements.

I must note briefly before continuing that to apply the term *technical writing* to these earlier centuries is technically anachronistic. Neither al-Khowarizmi nor Chaucer would have called what they did technical writing. The concept of Technical Writing as a job title (though O'Hara notes it was not yet recognized as a profession) at last came to rise in the era of the two World Wars.

Though industrial innovation and new scientific advances had bolstered technical communication in the past, the war era saw these factors energized through national defense spending. The United States, Britain, and other nations pumped funds into weapons, medicine, computing technology, transportation, and any other industry potentially useful to the military to get the edge on their opponents; it was in the wartime period that many modern innovations sprang forth as money and resources were funneled into the burgeoning military-industrial complex (O'Hara 2). Important as these inventions were, for both the scientific fields that created them and the militaries for which they were designed, these wartime advances also underlined the importance of the rising field of Technical Writing. Incomprehensibly complex new technology like the atom bomb and the computer needed documentation, specifications, and user instruction – and so writing rose as a critical skill for the scientist and the engineer in an early form of modern-day technical communication.

Technical writing continued to grow in utility in the post-war period, as the United States' economy, bolstered by wartime spending and expansion of industry, saw an increase in consumer goods. These goods included, importantly, many new forms of consumer-ready electronics thanks to the invention of the transistor in 1947, an innovation which allowed advanced devices to be smaller, more powerful, and significantly cheaper for purchasers (O'Hara 3). These purchasers, consumers generally lacking the technical expertise of scientists and engineers, needed documentation and manuals to explain these new technologies, and such newly necessary writing was firmly in the domain of the technical writer. While technical writing work began to enter the field of mass consumption, the military field continued to dominate its use as the Cold War drove the development of new defense technologies and scientific developments. This cycle of military innovations becoming consumer products maps much of the United States' development of technology, and the cycle served to cement the establishment of Technical Writing as a critical discipline in the professional environment.

At this point in American history, technical writing was a generally recognized type of work, but it still was not seen as its own field of *writing*. One can understand the reductive historical view as placing stress on the wrong half of the term: instead of technical ***writing***, the job was perceived as ***technical*** writing, an extension of technical work in the sciences and engineering. The common definition of technical writing as a tangential subskill resulted in dismissive attitudes towards the field, attitudes most often captured in the historical record by those who instead opposed them. Morris Freedman, an English professor at the University of New Mexico, noted in 1959:

> Technical writing occupies a curious status today. It is not quite an independent profession, yet many companies, indeed some industries, find that they cannot function without divisions devoted to various forms of technical writing and editing. In spite of this, they regard technical writers not quite as technicians, not quite as writers…
>
> Since the profession is a very new one, few persons have entered it directly. Most technical writers are refugees from engineering and science, from writing, or from the teaching of English. Like most refugees, the technical writer has not fled under the happiest of circumstances, nor does he remain in exile often enough with a sense of having found his place. Many technical writers who were converted from would-be poets or novelists, or from the teaching of English, yearn to get back to their original pastures. I presume that there must be some frustrated scientists and engineers who have similar yearnings (Freedman 53-54).

Freedman's account reveals the challenges obstructing Technical Writing's maturation into a respected field of writing. Such a field could not form when, as Freedman found, his contemporaries' definitions of technical writing not only failed to grasp the importance of writing but also misunderstood the nature of writing completely. Discussing the state of Technical Writing education, he argued that engineering and science classes' propensity to neglect the humanities led to students having "only the remotest idea of what writing involves. [They] will confuse writing with having a large vocabulary and knowing the rules of syntax and punctuation, capacities which many illiterate persons can achieve quickly and easily" (Freedman 54). Freedman feared such a conflation of the word *writing* in technical writing with stenography, worrying about the tendency of both STEM and English faculty to limit writing instruction for engineers to transcription. Internal conflicts like these held back both writers and engineers.

Conflicts on the importance of writing to technical writing, and conflicts on technical writing's place as either a technical job or a writer's job, appear in other academic discussions of the time. The 1962 National PGEWS Symposium raised the question in its title: "Engineering Writing and Speech: An Art or a Science?" Opinions clashed. In the second presentation of the symposium, Edward Galinsky of IBM declared, "Does the technical writer clarify and improve the engineer's material, or does he destroy the true meaning?... In that the argument is continuing, both sides must be right." His speech approached technical writers almost as an invasive species encroaching on the engineer's territory; the writer, in Galinsky's view, muddles the engineer's meanings in egoistic fits of overconfident self-expression when they should instead restrain themself to checking for misspellings and inaccurate punctuation (Galinsky 7). Galinsky's attitude, nigh-on hostile, is too fringe for us to extrapolate other contemporary reactions towards technical writing from it directly, but his central uncertainty (put mildly) towards the validity of technical writing as a profession does track with contemporary academics' records of the times. While some were suspicious of technical writing, still others were uncertain of its existence. W. Earl Britton wrote in 1965 about his experiences in discussing technical writing with academic peers:

> ALTHOUGH THE DEAN of an engineering college once denied the very existence of technical writing, many of us are confident of its reality. But we are not sure that we can convince others of its uniqueness. This uncertainty deepens when we observe the variety of activities incorporated under this label, as well as those that barely elude its scope… In view of the confusion, there is little wonder that a teacher in this field should often be asked, even by colleagues, "What is this technical writing you teach, and how does it differ from any other?" (Britton 113).

One may recall, from the earliest parts of our definition development, a challenge in categorizing technical writing near identical to what Britton recounts here; that is, technical writing's boundaries in the sense of content are too indistinct to be used to define it. From the lack of definition Britton captures the difficulty of grasping Technical Writing as a discipline: neither unfortunately unnamed dean of engineering nor fellow faculty in the realm of English were ready to recognize Technical Writing and claim it as their own. From suspicion to hostility to doubt, the long-running but only newly named field seemed in danger of being smothered in the proverbial cradle, and, as stories of confusion and ambiguity show, the greatest culprit was the lack of a clear definition.

If it was a definition the new and mysterious field of Technical Writing called for, then it was a definition its academic proponents were going to find. Britton, for example, followed his mournful tale of his colleague's failure to understand technical writing by positing "In addition to satisfying this query, a truly helpful definition should go much further and illuminate the tasks of both the teachers and authors of technical writing" (Britton 113). Britton's latter point illustrates another argument for the necessity of a workable definition beyond what his predecessors had created: technical writers - demonstrably needed boundaries to clarify and validate their work, but first their teachers needed - a structured definition so they could pass it down to their Technical Writing students. Britton suggested such a structure himself: "I should like to propose that the primary, though certainly not the sole, characteristic of technical and scientific writing lies in the effort of the author to convey one meaning and only one meaning in what he says… And the reader must be given no choice of meanings" (114). Britton's definition, though impressive for an early invention, is still imprecise. He asserts accurately that clarity is a key feature of technical writing but, on its own, clarity does not distinguish a piece of writing as technical writing. Nevertheless, Britton's shift of the definition of technical writing, placing the focus squarely on the writing half of the phrase, was a major step forward in furthering the understanding of the discipline. As a new field, Technical Writing depended on teachers adopting and spreading it to legitimize it professionally, and English professors like Britton were often the ones quickest to aid it by developing its definition.

Engineers during this time also began to consider the need for a stronger Technical Writing. At the same conference where Galinsky decried the interfering technical writer and the havoc they wreaked on the engineer's work, George Arnold of the now defunct defense contractor Sperry Rand Corporation delivered a presentation on the art of technical writing. Arnold, rather than choosing to offer an explicit definition, chose to discuss the principles of good technical writing, but these early principles are what implicitly form most common modern definitions. In a flashback to the previously discussed guidelines from the American Institutes for Research (or, in a historical sense, a flashforward), Arnold argued for the return of personal pronouns and active voice to technical writing, as in his view "the circumlocutions we have invented to avoid them in engineering prose have not improved our writing efforts" (Arnold 1). He also pushed for writing principles of concision both in presenting overall information and on a sentence-to-sentence basis, a writing idea not directly mentioned in the AIR guidelines but reflecting Britton's call for clear, unambiguous writing. Arnold's principle-based approach to discussing technical writing, as opposed to focusing on its subject matter, demonstrates Couture's idea of a "rhetorical category." By creating a framework for technical writing based on its key elements, Arnold defined the discipline in every sense except calling it a definition.

Arnold's principles for the improvement on technical writing on writing grounds clashed with Galinsky's desire for less editing of engineers' writing by technical writers. Whereas Galinsky argued that technical writers often twisted the meanings of their subjects, Arnold believed "what passes for engineering writing today [as] too rigid, dehumanized and deliberately anti-artistic" (1). When considered in the light of our formulated definition of technical writing, Arnold's argument here expands Britton's definition to resemble something closer to ours by bringing in the idea of flexibility. By adding flexibility to clarity, Arnold's principles for better technical writing demonstrate an understanding of the need to write for other audiences and other formats beyond that which a singular engineer might personally encounter: "Too often we assume a narrow, restricted audience. It is easy to assume that the person reading our words on paper will have the same background and knowledge of the subject that we have" (5). Besides expanding on Britton's definition, Arnold again clashed with Galinsky's idea of the infallible engineer. Even the cleverest engineer could not predict every tech illiterate audience who might eventually need to read his data, and it was for these users outside the engineer's sphere of jargon that the technical writer wrote. Arnold's user-focused approach to technical writing was forward-thinking for its time, clashing directly against the wider professional attitudes towards the discipline. History has made it quite clear which approach to the field won out, as the concepts and styles for which Arnold advocated still appear in modern technical writing and Technical Writing education.

The developing discourse around technical writing, propelled by academics like Britton and Arnold, continued to mature as the years advanced. Britton in particular remained relevant. Even though he was but one voice among many calling for a new definition of technical writing, his work was directly cited and expanded upon by other writers in later, more developed analyses. One of these writers, David Dobrin, a professor of Technical Communication, approached the field by asking what makes a piece of writing *technical*: "'Technical,' rather, has the force of an adjective; there is something about the writing itself which is technical… An adequate answer to the question, 'What's technical about technical writing?' is a definition of technical writing, and quite naturally, there have been many of them" (Dobrin 227). Dobrin examined three other contemporary definitions of technical writing, Britton's among them, and found them lacking. Two of them he dismissed as vague to the point of uselessness: "They are simple because they define a difficult concept in terms which are equally difficult and then leave those terms undefined" (228). Britton's call for technical writing to "convey one meaning and only one meaning in what he says," on the other hand, received special attention. Dobrin did not reject Britton's definition like the others, but he did note that it lacked nuance, arguing that it missed the complexity of context in language and the subtlety of meanings that even superficially simple messages carry. From this criticism Dobrin produced, through a lengthy philosophical discussion on the universalist and monadist views of language too abstract to be important here, a simple definition that better captured the essence of the field: "Technical writing is writing that accommodates technology to the user." Dobrin specified that the key word of his definition was *writing* and explained the use of *technology* in the definition: "'Technology' is more that an array of tools or procedures. It extends to the way human beings deploy themselves in the use and production of material goods and services" (242-243). Dobrin's choice to separate these elements from the definition itself is perhaps somewhat messy, but the elements themselves are critical to Dobrin's well-rounded definition of technical writing.

One can observe in Dobrin's definition, and in his addendums, many of the key ideas seen in more recent works which I in turn used to develop this paper's definition of technical writing. Most important of these ideas is the centrality of *writing* in technical writing, Dobrin's essay helpfully spelling out directly what other writers had been arguing for decades. Also important in his definition is the rhetorical emphasis on user-focused writing and specifically the principles I have called *clarity* and *flexibility* that center technical writing in practice around the needs of the user (presciently, Dobrin used the term "accommodation" almost a decade before Couture, backed by research, used it in her own contribution to the discourse). Even Dobrin's definition of technology, which he acknowledged as still indistinct, demonstrates technical writing's relationship with science and engineering: not defined by or totally beholden to those fields, but applied to them, and fields like them, in the sense that it makes them accessible to the user in ways common among all of them. Dobrin's definition is the last this paper will dwell on; his nuanced conclusion effectively reflects the culmination of half a century of academic debate and scholarly research to define technical writing as what it is today.

Though Britton, Arnold, Dobrin, and Couture are not the only writers to have shaped the modern understanding of technical writing, or even necessarily the most important ones, the path their arguments trace across the decades demonstrates the cumulative accomplishment of academics in producing today's understanding of the discipline. Technical Writing's literal roots could be traced to the earliest writers of ancient Egypt and Greece, to Gutenberg's introduction of the form to the English-speaking world, or to the explosion of new technologies in the World War and postwar eras that produced the field in its modern form. The field, as we know it, would likely not be the same if not for the scholarly voices who worked to elevate it, first as a distinct form of writing, then as writing that, in Dobrin's words, "accommodates technology to the user." A thorough understanding of technical writing's history must recognize the work that made it the well-established and thriving professional discipline it is today.

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Alginate microgels created by electrohydrodynamic jetting

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Abstract - Developing a facile process that can produce small hydrogels of a well-defined shape with diameters in the order of 100 μm is of great interest in the field of biomedical applications including drug delivery, tissue engineering, and cell manufacturing. We attempted to employ electrohydrodynamic (EHD) jetting process to fabricate such microgels made of sodium alginate. To achieve the controlled sizes and shapes of the microgels in a reproducible manner, the solution parameters (sodium alginate concentration, calcium chloride concentration) as well as operational parameters of EHD jetting (flow rate, voltage, distance between the jetting nozzle to the substrate) have been studied and optimized to yield a jetting condition with the sustained Taylor cone-jet mode. The morphology and the size of the resulting microgels for varying conditions were characterized by optical microscopy. The developed microgels can be employed as a biological reactor within which immune cells such as B cells can be manufactured for cellular immunotherapies for infections or autoimmune diseases.

I. Introduction

Electrohydrodynamic (EHD) jetting is used in order to produce micro- and nano-materials for several fields such as medicine, pharmaceutics, and bioengineering (Xie et al., 2015). In EHD jetting, a high electric voltage is applied to a jetting liquid, and the resulting electrical field drives a charged jetting liquid to travel towards the grounded electrode. When a positive voltage is applied to a polymer solution as the jetting liquid, positive charge accumulates on the surface of the meniscus of the liquid droplet, which changes the shape of the meniscus look like a cone (Taylor cone). Above a certain maximum electric potential, the electrostatic repulsion forces eventually break the surface tension of the droplet, and a jet of the solution is ejected and moves towards the electrode (Kim et al., 2009).

Sodium alginate is derived from seaweed and is a natural polysaccharide and is a structural polymer in the cell wall of seaweed. The alginate polymer, when in contact with divalent cations, forms hydrogels as a result of ionic cross-linking (Hench and Jones, 2005). When sodium alginate is in contact with a solution containing divalent cations such Ca^{2+}, a single calcium ion conjugates with two carbonate ions from neighboring repeating units of alginate polymers. This can happen throughout a mixture of multiple polymer chains in a solution, which is called cross-linking (Rowley, Madlambayan and Mooney, 1999).

When the solution of sodium alginate, our choice of polymer in the jetting solution, leaves the jetting capillary, the resulting jet falls into a collecting calcium chloride ($CaCl_2$) solution that is placed directly below the jetting capillary. The microgels are formed in the calcium chloride solution due to ionotropic crosslinking mentioned above (Park et al., 2012). In order to achieve a stable cone-jet mode, various concentrations of alginate solutions as well as several operational parameters such as voltage, diameter of jetting capillary, flow rate, and the distance between the jetting capillary and the collector with $CaCl_2$ solution were tested. The controlled jetting mode would be required to create microgels of defined shapes. The defined shapes could be either a conventional spherical shape or some non-spherical shapes. The non-spherical microgels could be interesting due to their anisotropic responses to the external forces as well as their unconventional surface profiles (Hu, Azadi and Ardekani, 2015).

The alginate microgels is advantageous for various biomedical applications due to its biocompatibility and biodegradability. They are useful as a means of delivery for bioactive macromolecular compounds as well as living cells (Kikuchi et al., 1999).

II. Experimental Procedure

Materials

Sodium alginate from brown algae (M_n≈80-120 kDa, M/G = 1.56) was purchased from Sigma-Aldrich and used without any further purification. Corresponding amount of alginate polymer powder was dissolved in ultrapure water, phosphate-buffered saline (PBS) buffer, or saline solution (0.9 % (w/v) of sodium chloride) at least 24 hours before jetting experiment.

Characterization

The resulting microgels were examined under an optical microscope (EVOS FL Auto, Life Technologies). The diameter of the microgels was measured from the optical microscope images. A ruler was placed directly on the computer monitor and the measurements of the diameters were recorded in MS-Excel. The measured values were calibrated using the scale generated by the microscope. The average diameter was calculated by observing a sample size of minimum 20 microgels. The viscosity of jetting solutions was measured by Mars 60 Rheometer (HAAKE, Thermo Fisher) equipped with titanium cone and plate (20 mm diameter and 2° angle) (Sánchez-Morán et al. 2019). All measurements were carried out at 37 °C.

EHD Jetting

The EHD jetting system is composed of a programmable syringe-pump (SyringePumpPro), a high voltage power supply (Gamma High Voltages), a charged coupled device (CCD) camera (DinoLite), a set of hypodermic needles (19 gauge), a light source, and a computer (**Figure 1**).

For a typical EHD jetting, the jetting solution of sodium alginate (0.5%w/v - 4.0%w/v) are supplied through a capillary at a flow rate (1.5mL/h -4.5 mL/h), while a high voltage (12.3 kV - 24.7kV) is applied to the jetting capillary. The distance (8.0 cm -9.0 cm) between the jetting capillary and the collecting substrate is adjusted as well. As a collecting substrate, a square (5.0 cm x 5.0 cm) piece of aluminum foil or 0.1M $CaCl_2$ solution in a grounded metal container was

n alginate.

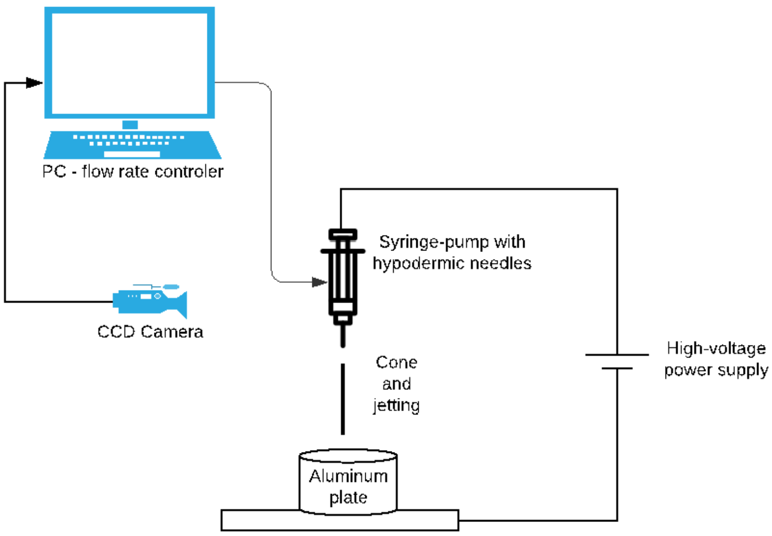

Figure 1. *Schematic diagram of EHD jetting setup.*

III. Results and discussion

EHD jetting in dripping mode

Effect of alginate concentrations.

The effect of alginate concentration and microgel size created by EHD jetting in dripping mode was investigated, as shown in **Figure 2 and 3**. **Figure 2** shows the representative microscope images of microgels made from alginate solutions of different concentrations employed as jetting liquids. The EHD jetting in dripping mode was achieved when 1.5 mL/hr flow rate, 8 cm height between the needle and the collecting substrate with calcium chloride solution, and the voltage of 12.3 kV were employed as critical working parameters. Different morphologies of microgels were observed. It is clear to observe that increasing alginate concentration leads to an increment of microgel diameter (**Figure 3**), which agrees well with the previous findings (Gryshkov et al., 2014). A more unstable fluctuation in the dripping mode was observed at 0.5 % alginate solution, causing a wider size distribution of microgels. It was also interesting to observe that non-spherical microgels were fabricated from jetting of 0.5 and 1.0 % alginate solutions. The resulting microgels demonstrated unique morphologies: mushroom-like (**Figure 2A**), bowl–like (**Figure 2B**), or spheres (**Figure 2C and 2D**). The mushroom- or bowl-like particles are anisotropic in their shapes and dimensions (**Figure 2A and 2B**). The mushroom-like particles have two different sides of longer axis (y-axis in **Figure 2A**), one side with smooth periphery (like the cap of mushroom), and the other side with a slightly bulging stalk. The bowl-like shape is very similar to the mushroom-like, except that one side of longer axis is simply flat without the stalk (**Figure 2B**). For the reporting purpose, the minimum diameter (the shorted axis) of the mushroom-like and bowl-like particle was measured (arrows in **Figure 2A and 2B**).

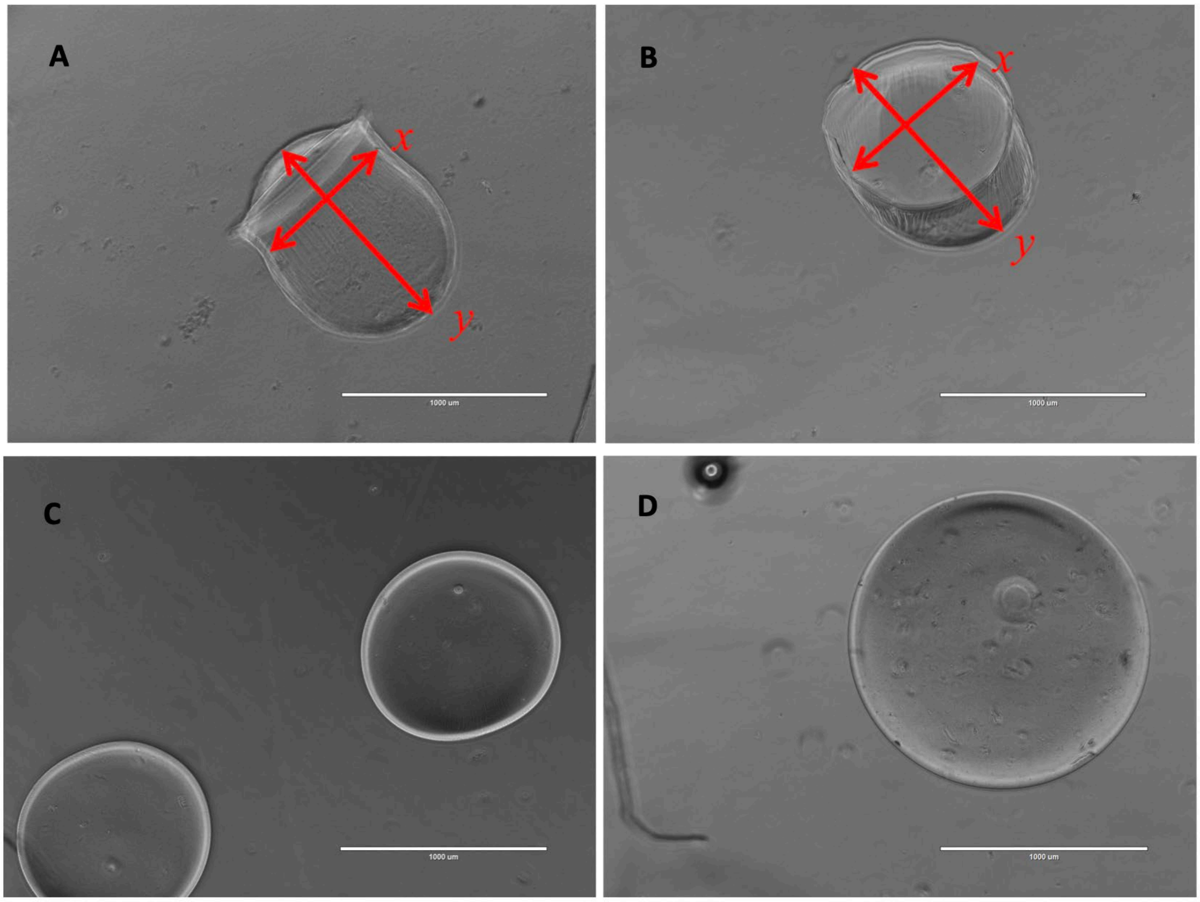

Figure 2. *Optical microscope images of microgels that are created by EHD jetting in dripping mode using different concentrations of alginate solutions as jetting liquids.* **(A)** *0.5,* **(B)** *1.0,* **(C)** *2.0, and* **(D)** *4.0 % (w/v) alginate solutions. The scale bar represents 1,000 μm. Red lines are added rendering to indicate the corresponding axis* **(A and B)**.

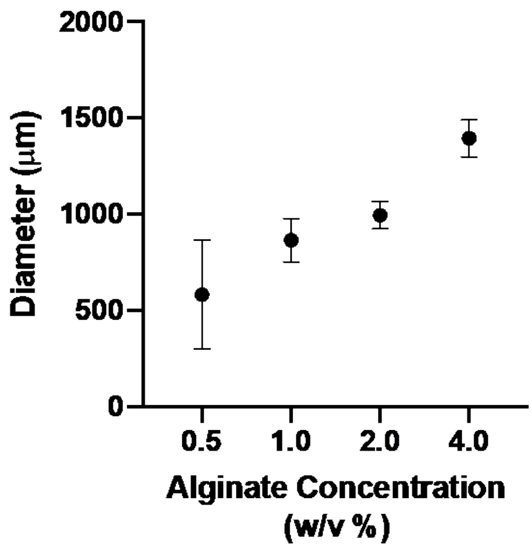

Figure 3. *Effect of alginate concentration on the diameter of resulting microgel made by EHD jetting in dripping mode.*

Effect of flow rates.

We evaluated how the flow rates in EHD jetting affect the size of the resulting microgels. Jetting solutions of a constant alginate concentration of 2.0 % (w/v) were employed in EHD jetting in dripping mode at four different flow rates, while all other working parameters remained constant, i.e. the collecting height of 8.0 cm and voltage of 12.3 kV. It is generally accepted that the flow rate of EHD jetting and the size of resulting micro-objects show a positive correlation. However, it was observed that an increase of flow rates from 1.5 up to 4.5 ml/hr caused only a slight variation in the size of the resulting microgels, which agrees to a previous literature describing the EHD jetting of alginate solutions (Gryshkov et al., 2014). Even if the size of the microgel was not significantly changed by the flow rate, the polydispersities in size significantly increased as higher flow rates are employed (**Figure 4**).

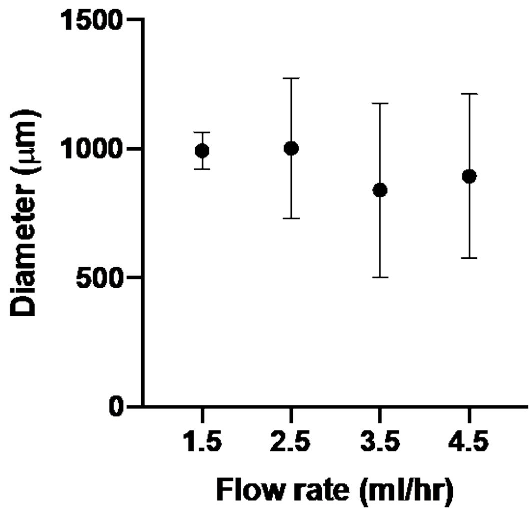

Figure 4. *Effect of flow rate on the diameter of resulting microgel made by EHD jetting in dripping mode.*

Transition of jetting modes from dripping mode to cone-jet mode.

In the present study, we attempt to achieve jetting conditions to generate and attain stable jetting that can produce microgels with a near-uniform size distribution. As we could not achieve this goal with dripping mode, we tried to achieve a stable cone-jet mode. As a comparative approach to achieve a cone-jet mode, the viscosity of sodium alginate solution was compared to the viscosity of other jetting solutions that yield a stable cone-jet. For example, a solution of poly(acrylamide-co-acrylic acid) with 20.39 mPa·s yielded a very stable cone-jet (Roh, Yoshida and Lahann, 2007). In a viscosity measurement, 0.7 % (w/v) alginate solution was 11.36 mPa·s. In fact, with the alginate solutions below 1.0 % (w/v), we could achieve EHD jetting with a stable cone-jet mode when much higher voltage (above 20 kV) is applied compared to the dripping mode (around 12 kV). The microgels acquired from cone-jet mode were significantly smaller with much narrower size distributions, compared to the microgels acquired from dripping mode (**Figure 5**).

In addition, if the stable EHD jetting with cone-jet mode can be achieved using alginate solutions prepared with a physiological saline or phosphate buffered saline (PBS). The varying working parameters, the composition of jetting solutions, and the characteristics of resulting microgels from 6 different EHD jetting experiments shown in **Figure 5** are summarized in **Table 1**. The representative microscope images of the resulting microgels are also shown in **Figure 6**. It is noteworthy that the morphology and size of the microgels were significantly varied by employing different jetting modes and varying parameters (solvent, voltage, flow rate and collecting height), even for the same concentration (1%, w/v) of sodium alginate (conditions 1, 5, and 6 in **Table 1**). Indeed, 1.0 % (w/v) alginate solution either in saline or PBS could generate a very stable cone-jet to yield spherical microgels with diameters of approximately 150 μm. This result is significant because the EHD jetting at the same condition now can be applied with living cells suspended in the jetting solution to create the microgels containing living cells. Such microgels containing living cells can be developed as a microcarrier or a microbioreactors for various applications.

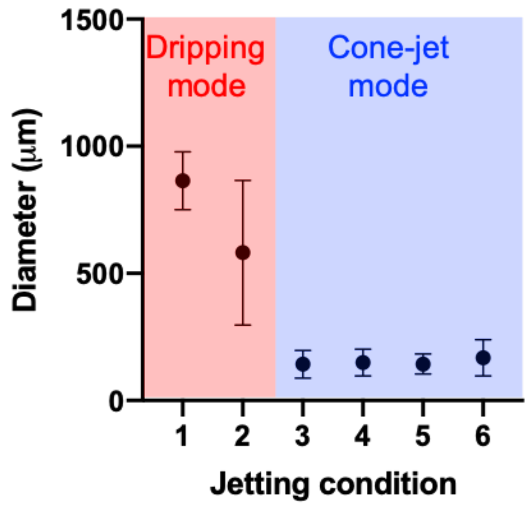

Figure 5. *A drastic reduction in size and size distribution (dispersity) of the resulting microgels by shifting the jetting mode from dripping mode to cone-jet mode.*

Table 1. *Different jetting parameters and conditions and the corresponding size and shape of the resulting microgels.*

Condition	Alginate Concentration (w/v%)	Solvent	Voltage (kV)	Flow rate (ml/hr)	Collecting height (cm)	Diameter (µm, mean ± std)	Morphology
1	1.0	Ultrapure water	12.3	1.5	8.0	864.3±113.2	Bowl
2	0.5	Ultrapure water	12.3	1.5	8.0	581.5±581.5	Mushroom
3	0.7	Ultrapure water	21.5	3.4	9.0	142.6±54.1	Bowl
4	0.5	Ultrapure water	24.0	3.8	9.0	149.77±52.3	Bowl
5	1.0	Saline	24.7	3.8	9.0	143.4±39.6	Sphere
6	1.0	PBS	24.3	3.8	9.0	168.2±71	Sphere

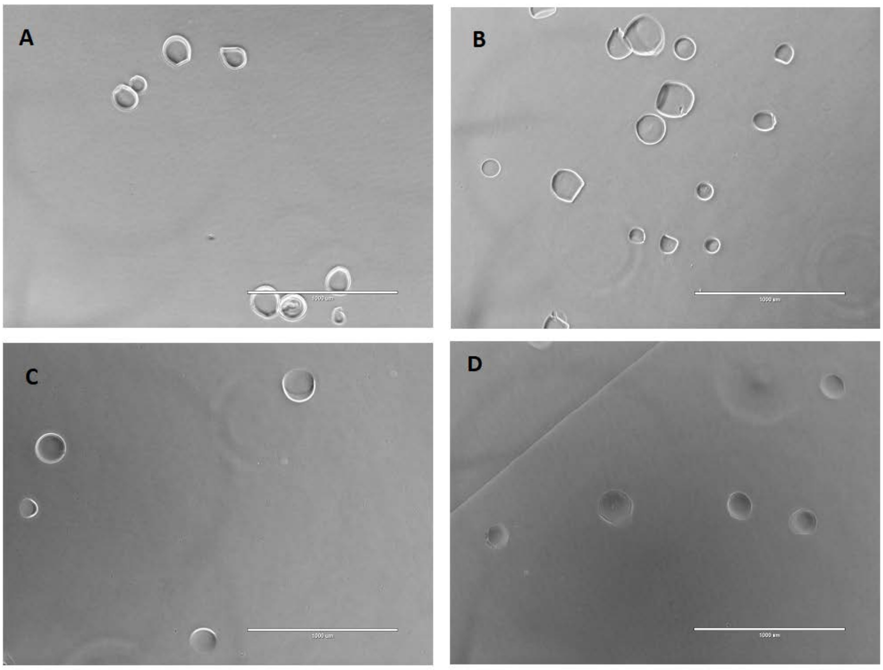

Figure 6. *Optical microscope images of microgels that are created by EHD jetting in cone-jet mode.* **(A)** *0.5 % (w/v) alginate solution in ultrapure water,* **(B)** *0.7 % (w/v) alginate solution in ultrapure water,* **(C)** *1.0 % (w/v) alginate solution in PBS, and* **(D)** *1 % (w/v) alginate solution in isotonic saline. The scale bar represents 1,000 µm.*

IV. Conclusion

Here we demonstrated a series of EHD jetting conditions that can yield a production of small hydrogels (microgels) of well-defined shapes. By selecting and controlling the working parameters and jetting parameters, not only the size and size distribution but also the morphology of the resulting microgels could be varied. The microgels of mushroom-like, bowl-like, and spherical shape could be useful for various applications (Gao et al., 2015). Alginate microgels of uniform shape and size can be created using physiologically relevant jetting parameters demonstrates that the technology described here could potentially be further developed as microbioreactors for various cellular engineering applications such as manufacturing of therapeutic cells (Mendoza García, Izadifar and Chen, 2017).

V. Acknowledgements

BM would like to thank all members of Roh Lab for accommodating this research initiative, their kind assistance, and sharing knowledge freely in the lab. BM gives special thanks to Jet Tan for the initial training on EHD jetting.

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The Effects of Sea Level Rise on Health and Displacement in the Pacific Northwest

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Abstract - Coastal Washington and Oregon are vulnerable to future inundation due to sea level rise. Inundation would most likely lead to people displaced from their homes and lead to health issues of both mental and physical natures. Using ArcMap, areas most likely to be inundated were identified and the number of people that may be displaced were estimated for 1, 2, and 5 ft of sea level rise scenarios. The amount of Native Americans who live on federally recognized reservations and entities that may be displaced was also estimated. It was found that many of the inundated areas, particularly those within reservations or entities, were in medically underserved areas and health professional shortage areas. It was found that over 200,000 people would be displaced by 1 ft of sea level rise, over 225,000 people by 2 ft, and over 300,000 people by 5 ft. Of those displaced, over 2,100 Native Americans who live on reservations or entities would be displaced by 1 ft of sea level rise, 3,700 Native Americans by 2 ft, and 5,900 Native Americans by 5 ft. About a third of those displaced live in medically underserved areas and over two thirds live in areas that lack primary care and mental health professionals.

I. Introduction

Sea level rise (SLR) and the subsequent flooding poses a threat to many coastal communities around the world. While it is difficult to quantify the amount of people that will actually be impacted by SLR, it is important to explore possible scenarios. In doing so, a baseline for how many people and what communities will be impacted by future inundation due to SLR events can be formed. It is important to ensure that the impacts of SLR on underserved communities, such as indigenous peoples, are being explored in order to assess where aid is needed most.

Coastal Washington and Oregon will experience sea level rise related inundation and the consequences that accompany it. It is important to look at the Pacific Northwest as the region has a long coastline of approximately 4,400 miles and a population of 5.5 million that lives near the coast (*The Coast of the United States, 1975; Washington, n.d.; Oregon, n.d.*). Furthermore, Washington and Oregon have significant Native American populations with reservations or entities along the coastline as indigenous communities are highly vulnerable to SLR and climate change (Ford, 2012). The Pacific Northwest also experiences the effects of the Pacific Decadal Oscillation and the El Nino Southern Oscillation which increase coastal hazards and would exacerbate the effects of sea level rise in the region (Dalton et al., 2013). This region is further vulnerable as it was found that with at least 10 centimeters (3.9 inches) of SLR, the flooding potential doubles for high latitude regions such as the Pacific Northwest (Vitousek et al., 2017).

Health issues arise in the aftermath of flooding and inundation, so it is reasonable to explore these eventualities. The health issues would be of both a physical and psychological nature as flooding and inundation can lead to increases in gastrointestinal and respiratory illnesses as well as mental ones such as PTSD, anxiety, and depression. However, not all areas are equally equipped to face these challenges Therefore, it is vital to explore the displacement and health impacts of sea level rise. Such an undertaking can allow for preparations to be made in advance so that communities, in conjunction with local, state, and federal authorities may have a better grasp of potential impacts. This includes predicting how many people will be displaced from their homes and how many people may need medical attention as a result. It also allows for communities to decide the best course of action for the future. Furthermore, informing underserved communities, such as Native Americans, of these potential risks prepares them to seek aid from government programs.

II. Methodology

Study Area

The Pacific Northwest is not as vulnerable to sea level rise as other regions such as the Gulf Coast due to its high elevation, but it will still experience the detrimental effects of it, such as displacement and illnesses (Gornitz et al., 1991). It is worth exploring inundation in this region since there is a vast population and shoreline that will experience the effects of SLR.

The Pacific Northwest will most likely experience between 0 and 2ft of SLR by 2100 (Dalton et al., 2013). Therefore, 1, 2, and 5 feet (ft) of SLR scenarios were explored with the 5 ft scenario as an extreme.

Data

Sea level rise data were obtained from NOAA's Office for Coastal Management. The datasets downloaded were the Mapping Confidence rasters that show confidence levels for inundation or dryness for 1, 2, and 5 ft of SLR for different coastal areas. This data was used to determine what areas are most at risk of inundation under the different SLR scenarios. Health Professional Shortage Areas (HPSA) and Medically Underserved Areas (MUA) shapefiles were downloaded from the United States Health Resources and Service Administration. The HPSA and MUA datasets were used to explore how many people may require medical attention and/or be displaced as a result of SLR. The HPSA shapefiles showed areas where there was a shortage of primary care or mental health professionals, and the MUA shapefile showed areas that are medically underserved in general. These areas are decided by the Health Resources and Services Administration's designation process which looks at variables such as clinical practice activity, hours worked at each location, provider practice locations, etc. in order to be considered medically underserved or have a shortage of healthcare professionals.

Population data were obtained from NASA's Socioeconomic Data and Application Center. The Gridded Population of the World Version 4: Population Count Adjusted to Match 2015 Revision of UN WPP Country Totals dataset was used to assess how many people could potentially be impacted by different SLR scenarios. The 30" resolution GeoTiff estimate for 2020 was used to model population counts in potentially inundated areas. The Social Vulnerability Index by census tract datasets for Washington and Oregon for 2010 was obtained from NOAA's Office for Coastal Management. This polygon dataset was also used to estimate the amount of people impacted by SLR. The American Indian Reservations/Federally Recognized Tribal Entities shapefile was obtained from the Bureau of Indian Affairs and displayed the reservations/entities as polygons and contained population data for each reservation. The data was used to estimate the number of Native Americans affected by SLR.

Methods

Data processing and manipulation was completed in ArcMap 10.5.1. First, all data was projected to North American Datum 1983 (2011) UTM Zone 10N. Next, cell values of high confidence levels for inundation were selected from the mapping confidence rasters; these high confidence values are values were mapped as inundated at least 80% of the time in the creation of the dataset. With these values selected, the rasters were converted into polygons and then all the polygons making up the coastline were merged. This process was done for 1 ft, 2 ft, and 5 ft of SLR. Then, the extract by mask tool was used to narrow the Gridded World Population data down to the study area. The American Indian Reservations/Federally Recognized Tribal Entities, Hospital, MUA, and HPSA datasets were clipped down to the Pacific Northwest as well.

Next, the number of people that would be displaced under the different sea level rise scenarios was calculated. First, the census tracts and inundation polygons were intersected, and the resulting layer was dissolved by census tract. This resulted in a polygon layer displaying where inundation overlapped with each census tract. Then, the Zonal Statistics as Table (ZST) tool was used to estimate the amount of people living within potentially inundated areas in each census tract based on the Gridded Population data. The ZST output table was joined to the census tracts layer, and the number of people displaced in each census tract was displayed based on Jenks which are groupings based on natural breaks in the data.

A similar process was used to estimate the number of people affected that are living on Federally Recognized Entities or American Indian Reservations using the respective shapefiles. The reservations/entities layer was intersected with the inundation and then dissolved by the Land Area Representation Name. Then, the ZST tool was run again to estimate the number of people living within potentially inundated areas of each reservation/entity, based on the Gridded Population data. The output table was joined to the reservations/entities layer and displayed based on the natural breaks within the data. These steps were run for 1ft, 2 ft, and 5 ft of SLR.

In order to identify areas that may experience a higher rate of health problems due to lack of access, the Medically Underserved Areas (MUA), the shortage of primary care professionals areas (PC), and the shortage of mental healthcare professionals areas (MH) datasets were first intersected with inundation. These intersections were calculated for each level of SLR. Then, intersected layers were dissolved by unique identifiers and the newly dissolved layers were used in the ZST tool with the Gridded Population dataset. This produced tables of how many people in each intersection combination would experience inundation and potentially be at a higher risk for health problems. This process was repeated for the intersection combinations of the reservations/entities dataset.

It is important to note that these are estimates and the methods used do have flaws. The predicted amount of people that would be impacted are likely overestimates as the Zonal Statistics as Table tool uses the whole value of a pixel in the Gridded World Population data when only part of the pixel experiences inundation leading to overestimation. Furthermore, there was no data available for the northwest corner of Washington which includes parts of Clallam, Grays Harbor, and Jefferson counties; this area also has reservations and entities that were not accounted for. These areas were not included in the estimates which could indicate an underestimate of displaced populations.

III. Results

SLR and Displacement

The estimates of how many people would be displaced by 1 ft, 2 ft, and 5 ft of sea level rise are shown in **Figure 2**. The color of each census tract displays the estimated range of people displaced. The areas that would be inundated are shown as well with a light blue color. An estimated 203,620 people are expected to be displaced by 1 ft of SLR, 227,751 people are estimated to be displaced by 2 ft of SLR, and 308,581 people are estimated to be displaced by 5 ft of SLR. The counties that have census tracts with the highest rates of displacement include Skagit, Snohomish, Grays Harbor, Wahkiakum, Cowlitz, Kitsap, Clatsop, Columbia, and Coos counties.

The estimate of how many people who live on Native American reservations/entities that would be displaced by 1 ft, 2 ft, and 5ft of SLR has been analyzed and visualized in **Figure 3**. Each affected reservation or entity is displayed with a color that represents the estimated range of people that could be displaced. The inundated areas are shown as well. An estimated 2,183 people who live on reservations/entities will be displaced by 1 ft of SLR, 3,755 people who live on reservations/entities are estimated to be displaced by 2 ft of SLR, and 5,964 people are estimated to be displaced by 5 ft of SLR. **Table 1** shows the amount of people for each reservation/entity that will be displaced by 1 ft, 2 ft, and 5ft of sea level rise with the Puyallup, Tulalip, and Lummi reservations/entities being the most impacted. **Table 2** shows the percentage of each population type, Native American or general, from affected counties that would be displaced. Native Americans are shown to be less likely to be displaced for 1 ft of SLR, but more likely to be displaced by 2 and 5 ft. However, **Table 2** accounts for displaced Native Americans that live on federal reservations/entities and does not include those who do not live on reservations/entities.

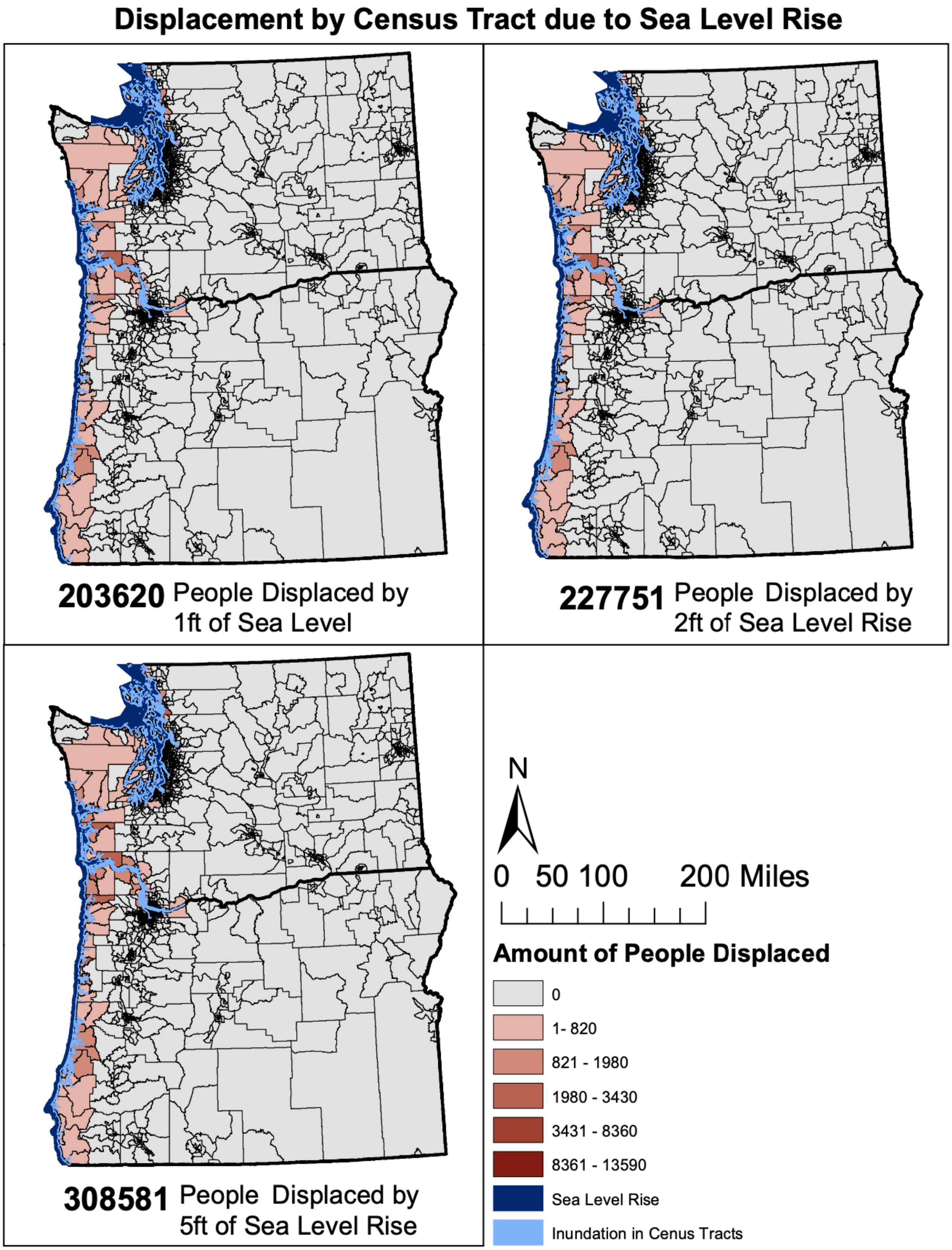

Figure 2. *The number of people displaced by census tract for 1 ft, 2 ft, and 5 ft of sea level rise.*

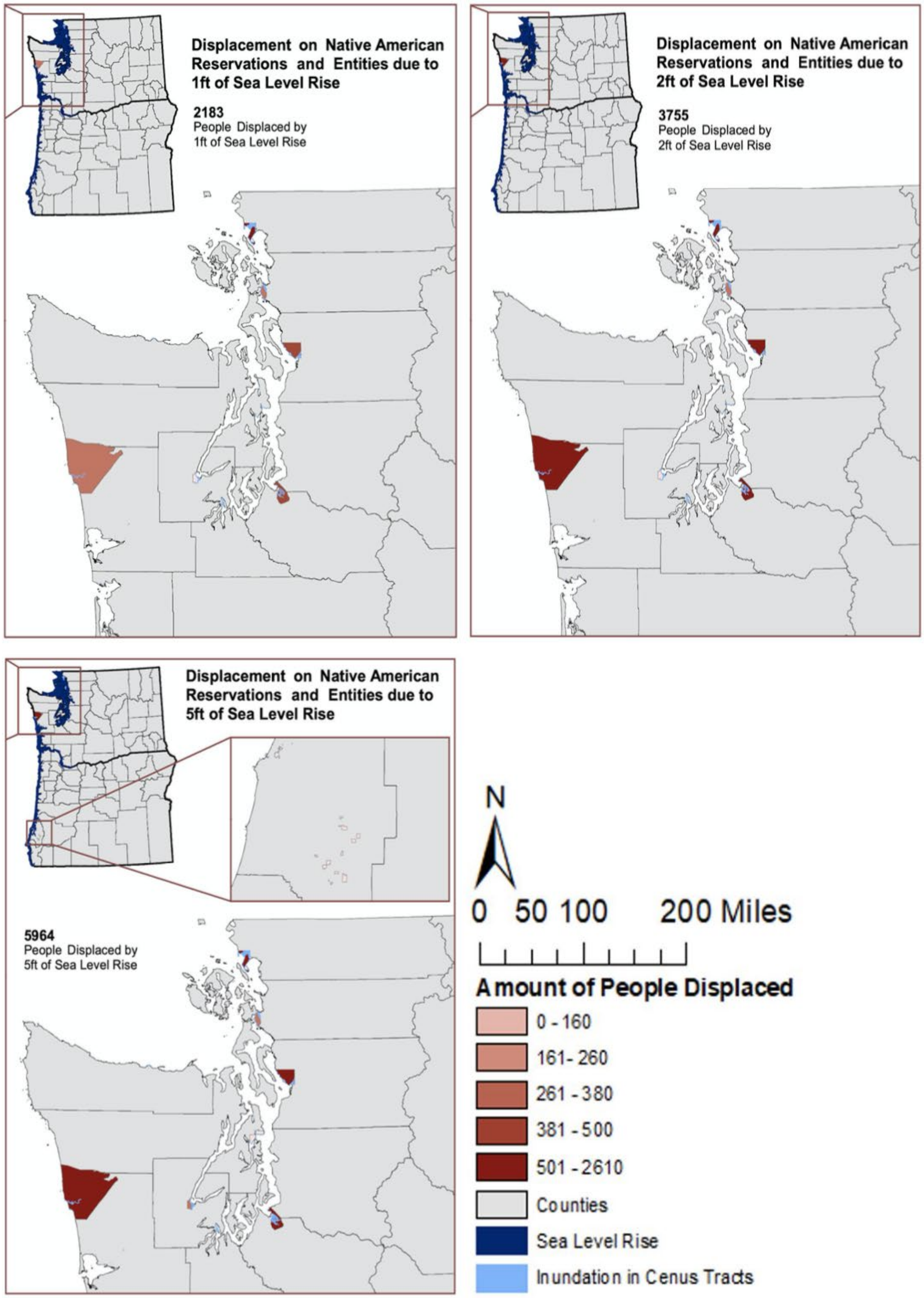

Figure 3. *The amount of people who live on each reservation/entity displaced by 1 ft, 2 ft, and 5ft of SLR.*

Table 1. *The amount of people estimated to be displaced in each reservation/entity.*

Reservation / Entity	Amount of People displaced by 1 ft SLR	People displaced by 2 ft SLR	People displaced by 5 ft SLR
Shoalwater	0	0	7
Port Madison	0	0	102
Coquille of Oregon	0	0	135
Skokomish	137	164	357
Swinomish	351	351	362
Quinault	261	525	516
Lummi	508	583	902
Tulalip	483	1451	977
Puyallup	444	683	2611

Table 2. *The percentage of each population type from the counties affected that will be displaced by SLR.*

Feet of SLR	% of Native American Population	% of General Population
1	2.48	3.09
2	4.27	3.46
5	6.79	4.68

SLR and Health

In inundated areas, approximately 30% of the people that would be displaced also reside in a medically underserved area, 70% of those displaced would be in an area that has a shortage of primary care professionals, and 90% of those displaced would be in an area that has a shortage of mental health professionals. Most inundated areas are in health professional shortage areas and almost half of inundated areas are in medically underserved areas. This is shown in **Figures 4, 5, and 6**.

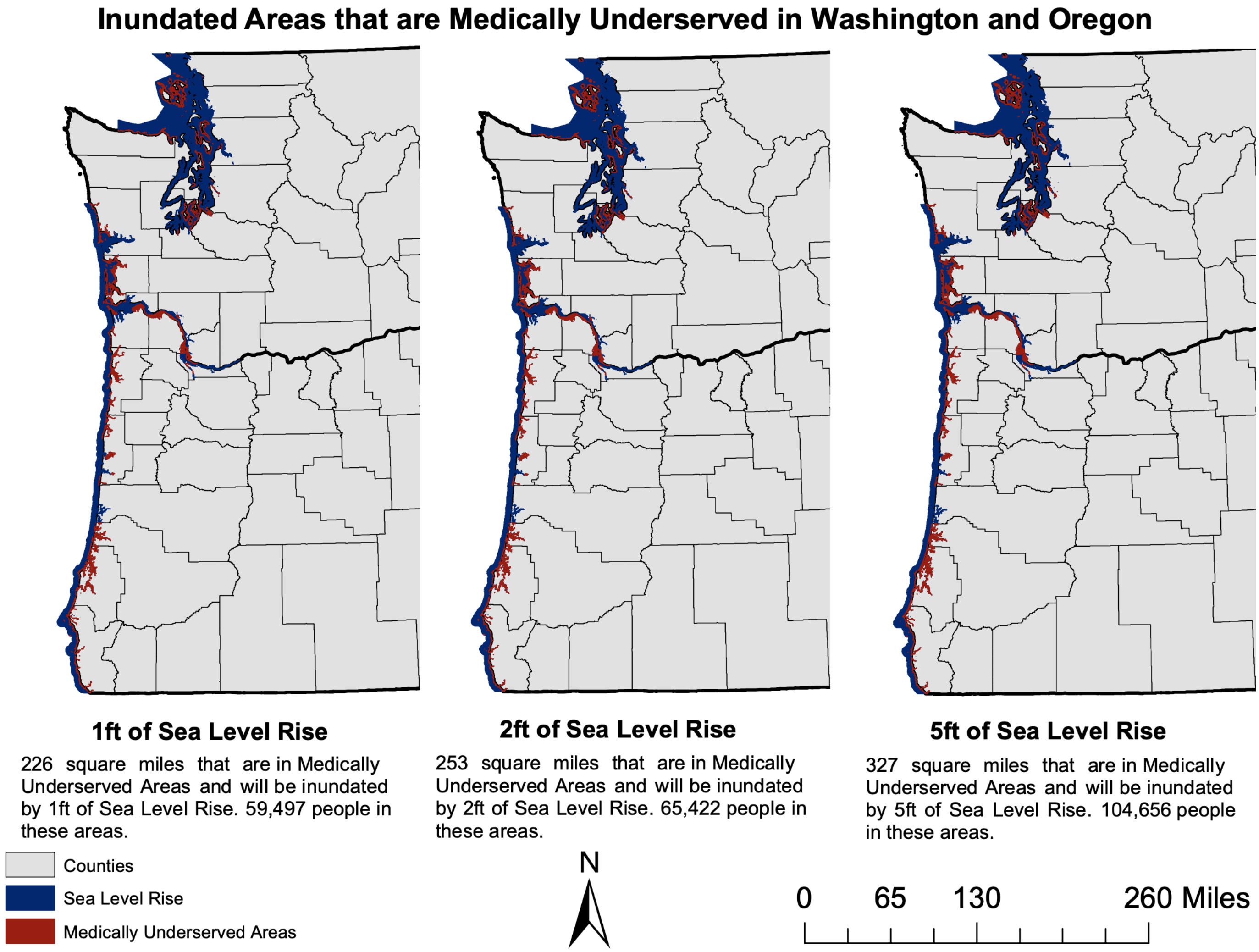

Figure 4. *Areas that could be inundated and are medically underserved.*

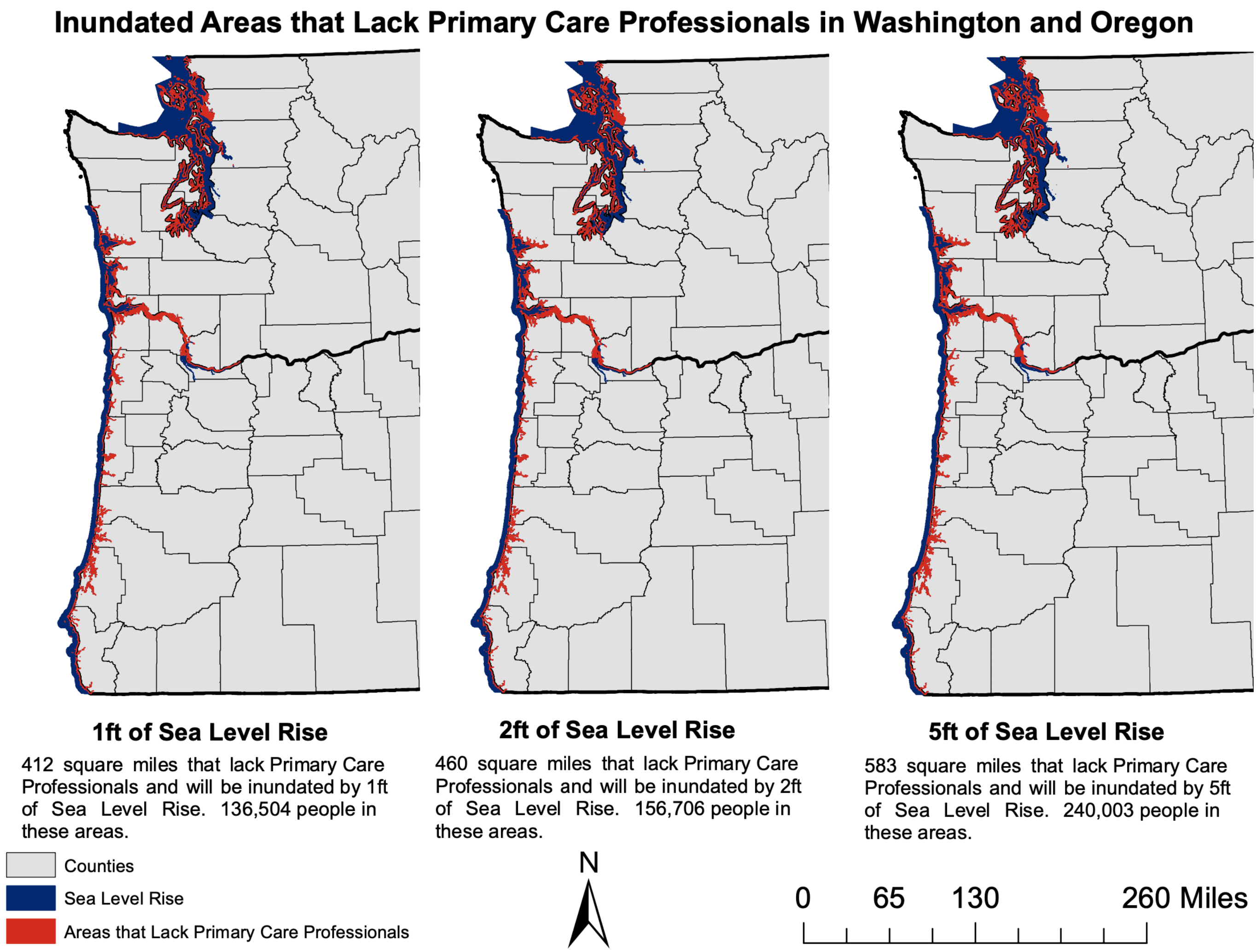

Figure 5. *Areas that could be inundated and lack Primary Care Professionals.*

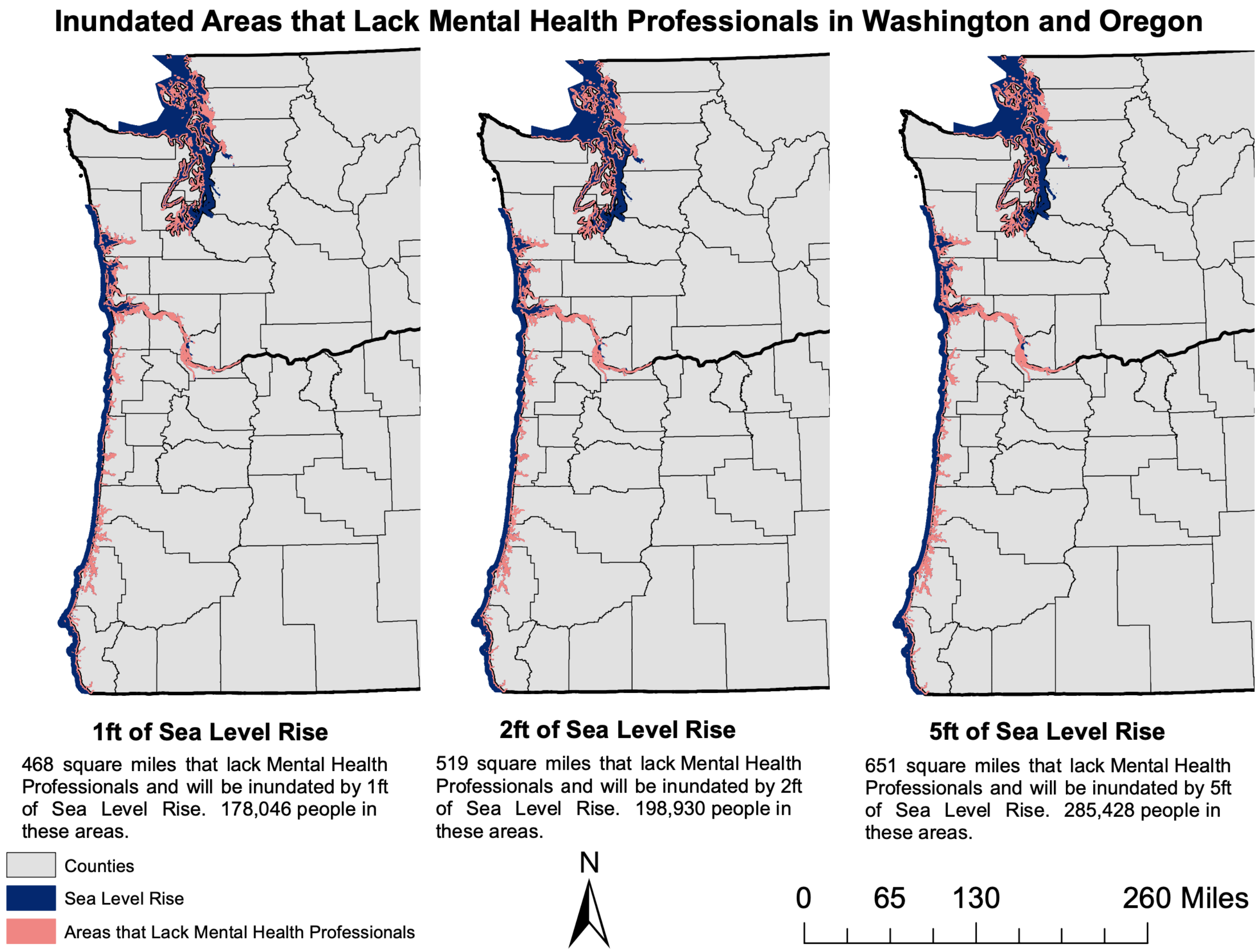

Figure 6. *Areas that could be inundated and lack Mental Health Professionals.*

Table 3. *The number of people that live in medically underserved areas and/or areas that lack healthcare professionals that will experience inundation.*

Feet of SLR	People in MUA and Inundation	People in PC and Inundation	People in MH and Inundation
1	59,498	136,504	178,047
2	65,422	156,706	198,930
5	104,656	240,003	285,429

Table 4. *The number of people who reside on reservations/entities in medically underserved areas and/or areas that lack healthcare professionals that will experience inundation.*

Feet of SLR	People in MUA and Inundation	People in PC and Inundation	People in MH and Inundation
1	705	1739	1739
2	1207	3072	3072
5	3369	3354	3354

IV. Discussion

The effect of sea level rise will be dire and extensive. Over 200,000 people will potentially be displaced due to 1 ft of SLR. The number of people that will face health and displacement challenges rises with the amount of SLR with over 225,000 people impacted by 2 ft of SLR and over 300,000 people impacted by 5 ft. Additionally, over 2,100 people who live on reservations/entities could be displaced by 1 ft of SLR, over 3,700 people by 2 ft, and 5,900 people by 5 ft. Although sea level rise is difficult to predict, especially for the Pacific Northwest, these estimates for the most likely scenarios (1 and 2 ft) in addition to an extreme (5 ft) hold value. The estimates can allow for proper preparations for funding and aid to be made in advance of the actual sea level rise events. Furthermore, separate preparations and aid can be made for underserved communities, such as Native Americans.

Many of the people that would experience inundation reside in medically underserved areas and health professional shortage areas. This means that many people who might experience inundation could have poor access to proper healthcare. Easy access to healthcare is a necessity because of the many health issues that arise due to inundation including anxiety, PTSD, depression, gastrointestinal illnesses, and respiratory illnesses. The identified areas can be targeted for funding for better healthcare and the introduction of more health professionals. For underserved communities that are more at risk of health issues, such as Native Americans, it is important that healthcare be prioritized.

V. Conclusion

The Pacific Northwest is just one area that will face sea level rise and inundation as a result. Hundreds of thousands of people may be affected. Despite the inability to calculate the exact number of people that will be displaced, the estimates of how many people and where they live can help communities and all levels of government prepare for sea level rise scenarios. Therefore, the damage and problems that might arise can be reduced or avoided before they occur. This research found that over 200,000 people in coastal Washington and Oregon may be displaced due to sea level rise. Native Americans in these states are particularly vulnerable with over 2,000 people at risk of displacement due to inundation on nine reservations/entities. The areas at risk of inundation, especially those within reservations/entities, fall with medically underserved areas and health professional shortage areas.

It is beneficial for the different levels of government as well as communities and the tribes affected to know these possibilities and where potentially displaced populations will be. A proper amount of time can be taken to assess how much aid will be needed and to evaluate solutions should a city, town, or reservation/entity need to be abandoned due to inundation. Additionally, the knowledge of which reservations and entities are in medically underserved areas or health professional shortage areas and which do not have easily accessible hospitals or healthcare centers can also help government administrations for planning aid allocation in the event of natural disasters or public health crises. This way tribes that are in medically underserved areas or lack health professionals may receive aid swiftly or be allotted funding. With this knowledge in hand, proper courses of action can be taken by both sides and a dialogue can be opened between communities and the government so that plans for aid and relocation can be made.

Additional research can be completed with sea level rise data that is specifically tailored to the Pacific Northwest and detailed population data to depict more accurate representation of where inundation may occur and how many people will be impacted. More sea level rise scenarios can be explored for up to ten feet of SLR to gain more insight into the amount of people that may be displaced. Furthermore, this research can be expanded further by looking at poverty, race, age, and social vulnerability rates for inundated areas so that communities that are more socially and economically vulnerable may be identified and aided in the event of sea level rise.

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