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Transformative Sea-Level Rise Research and Planning: Establishing a University, Tribal, and Community Partnership for a Resilient California North Coast

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Abstract

Sea-level rise (SLR) is and will continue to be a pressing issue in the rural, North Coast region of California, especially since nearby Wigi (or Humboldt Bay) is experiencing one of the fastest rates of relative SLR on the U.S. West Coast. In this paper, we argue that SLR presents a transformative opportunity to rekindle environmental relationships and reshape the future of the California North Coast and beyond. As the preeminent higher education institution of the region, Cal Poly Humboldt has the responsibility to be a leader in education, research, and planning for climate resilience. We describe efforts of the Cal Poly Humboldt Sea Level Rise Institute to establish a university-Tribal-community partnership that braids together different approaches and ways of knowing to develop research and planning that supports a resilient California North Coast. Since Wigi is projected to experience the effects of SLR sooner than the rest of the state, the North Coast region is poised to act as an incubator for new ideas and solutions, including Indigenous knowledge systems, and to play a role in influencing equitable, resilient, and transformative SLR adaptation processes in other parts of the state and the world. This will require developing programming and expertise in specific disciplinary areas, but, more importantly, will require the development of opportunities and spaces for various disciplines, ways of knowing, and sectors (e.g. Tribal nations, academia, government, NGOs, private companies, and community groups) to converge and bring the best of what they have to address climate-induced challenges and opportunities.

Keywords: sea-level rise, climate resilience, adaptation, transformation

A shift in thinking would open up the potential for climate change research to be a transformative moment, especially if democratized and inclusive of multiple forms of knowledge.

— *Hardy, Milligan, and Heynen 2017:71*

Hopefully all of us can work together [. . .] and we can help battle climate change and try to adapt.

— *Hilanea Wilkinson, Citizen of the Wiyot Tribe, Humboldt Bay Symposium 2021*

Sea-level rise (SLR) is an outcome of the global gclimate crisis. Recent studies estimate that up to 171 million people across the globe face risk of coastal flooding, but those figures are expected to jump to 204 million by 2050 and 253 million by 2100 (Plumer 2020). Even if global heating is limited to well below 2 °C, sea level will continue to rise. Global mean sea level has risen 20-23 cm since 1880 and the rate of rise has been accelerating. Since 1850, anthropogenic climate change has been the primary factor contributing to global sea level rise (Jevrejeva, Grinsted, and Moore 2009; Church et al. 2013). This rise is mostly attributed to the thermal expansion of seawater as it warms and meltwater from glaciers and ice sheets (Frederikse et al. 2020; Lindsey 2022; Oppenheimer et al. 2022). SLR is projected to have a large effect on the state, economy, and people of California (OPC 2018). The state, the nation, and the entire globe are in search of strategies and solutions to address this issue. SLR is and will continue to be a pressing issue in the rural North Coast region of California where Cal Poly Humboldt is located. For example, nearby Wigi[1] (or Humboldt Bay), which is part of the ancestral and present day territory of the Wiyot people, is experiencing the fastest rate of relative SLR on the U.S. West Coast (Anderson 2018). SLR has the potential to inundate critical infrastructure, residential, agricultural, industrial, and ecologically and culturally significant coastal lands in the region (Laird 2018b). These changes could lead to severe social, cultural, economic, and environmental harm without effective adaptive responses. Despite these risks, SLR presents people in our region with an opportunity to work together and envision a more just and resilient future.

This paper has been developed by academic, Tribal, community, and government members of the Cal Poly Humboldt Sea Level Rise Institute (SLRI), which formed as an interdisciplinary initiative in 2018. The goals of this paper are to (1) provide readers with an overview of SLR in the North Coast region, (2) provide a description of how different ways of thinking influence our approaches to SLR and some of the work that has been done locally to date, and (3) provide a vision for how Cal Poly Humboldt, in concert with Tribal, community, government, and private sector partners, can develop programming and approaches related to equitable, resilient, and transformative SLR education, research, planning, and action.

As we describe our vision for local SLR work into the future, we draw from the following definitions:

Equitable: Many scholars and practitioners have begun exploring the concept of equity in relation to marine and coastal systems or climate adaptation (e.g. Mohnot, Bishop, and Sanchez 2019; Bennett et al. 2021; Swanson 2021; Ajibade et al. 2022; Bibby and Carter 2022; OPC 2022). Equity has been defined as a "process that leads to the intended outcome of justice, which necessitates the reckoning, remedying, and prevention of sys-

1. Throughout the paper we will use term Wigi which is the Wiyot name for Humboldt Bay.

temic injustices" (Bibby and Carter 2022:11). We define equitable SLR planning and research as that which seeks justice and considers how SLR and SLR adaptation processes will interact with differences based on race, class, gender, sexuality, and ability among others. It prioritizes action in disadvantaged or frontline communities. Equitable planning processes seek to address historical inequities and are inclusive, incorporating Tribal leadership, community involvement, and multiple ways of knowing. Ajibade et al. (2022:8) further define just SLR adaptation processes as those that incorporate "self-determination, robust planning, collaborative decision making, land rights,…and attention to intersecting justice(s)."

Resilient: People are part of the natural world and we depend on ecosystems for survival. Resilience describes the ability of interconnected social-ecological systems to adapt to change and thrive in dynamic environments (Resilience Alliance 2023). Beatley (2009) defines coastal resilience specifically as composed of four planning dimensions: ecological, social, and economic resilience and resilience of land use and the built environment—all of which must be weighed and addressed in effective coastal planning. SLR planning for resilience is multi-dimensional, considering the longevity and effectiveness of potential adaptation measures in terms of protecting communities, local economies, infrastructure, ecosystems, and public safety in the face of dynamic coastal change. Planning for resilience considers the potential impacts of SLR adaptation actions on ecosystems, habitats, and species and seeks to develop solutions that address environmental impacts from SLR, such as the loss of coastal habitats from rising waters. As an example, planning for resilience may not prioritize the building of levees or sea walls around locations when those strategies could have significant negative environmental consequences (Dugan et al. 2011) or if those areas are projected to flood from rising groundwater just a short time after the structures are completed (Rotzoll and Fletcher 2013; Pierre-Louis 2021).

Transformative: Pelling (2011:83) introduces the concept of climate change "adaptation as transformation." He argues that "it is too easy to see adaptation as a narrowly defensive task—protecting core assets or functions from the risk of climate change," (Pelling 2011:i) and instead invites a shift in thinking toward viewing climate change adaptation as "an opportunity for social reform, for the questioning of values that drive inequalities in development and our unsustainable relationship with the environment" (Pelling 2011:3). For us, transformative SLR work is that which considers opportunities to disrupt the status quo and pursues forms of development and governance that overcome historic injustices, center equity, and reconstitute our relationship with the natural world. Transformative climate resilience work also invites opportunities for climate-induced challenges to change the way institutions (like Cal Poly Humboldt) and disciplines operate, how they seek and communicate knowledge, how they collaborate, how they make decisions, and how they wield, share, and re-center power.

Braiding Disciplines and Ways of Knowing

There has been much scholarship dedicated to the challenge of developing research and solutions to complex environmental issues that spill across disciplinary, sectoral, and knowledge boundaries (e.g. Rittel and Webber 1973; Cheng 2006; Weber, Lach, and Steel 2017). Scholars in academia have for decades recognized the need to bring together multiple disciplines in order to address environmental challenges, with a focus on bridging social and environmental approaches. The notion of interdisciplinarity or its cousin transdisciplinarity has "become a widespread mantra for research" (Klein 2008:S116) within many branches of academia. Scholarship reveals that inter- or trans-disciplinary environmental work has achieved many important breakthroughs, but has also run into challenges related to overcoming disciplinary and ontological divides and incorporating (or failing to incorporate) perspectives from communities outside of academia (Polk 2014, 2015; Gaziulusoy et al. 2016). Transdisciplinary scholarship can be a source of inspiration for SLR work locally as it typically involves the incorporation of multiple disciplines and knowledges, it is driven by societal and community needs, and it "presumes theoretical and methodological transformation of each discipline will take place through the process of research" (Gaziulusoy et al. 2016:56). Still, the centering of the word "discipline" in these terms forefronts the work as predominantly drawn from academic spaces and modes of thinking.

Starting around the late 1980s, scholars from the environmental fields began to increasingly acknowledge the existence and importance of multiple knowledge-types or ways of knowing the natural world (Bateson 1979; Berkes 1999; Barnhardt and Kawagley 2005). Academics defined the term local ecological knowledge (LEK) to describe the place-based and experiential knowledge that individuals or communities develop through their connections to ecosystems. Scholars also proposed the term Traditional Ecological Knowledge (TEK) to describe the environmental knowledge generated by Indigenous groups through their connection to and stewardship of environments over many generations (Johnson 1992; Berkes 1999; Berkes, Colding, and Folke 2000; Ramos 2021). Many of these same scholars have called for the "integration" of knowledge types to understand and address complex environmental issues (Berkes 1999, Reid et al. 2006). However, these integration approaches have drawn critique. Scholars point out that the term TEK was developed by Western scientists and it does not necessarily originate from or reflect the ways indigenous people describe their worldviews (McGregor 2005; Reed 2022). The notion of TEK has also been critiqued for being reductive—seeking to isolate environmental information or observations from the broader cultural and ethical context (Kimmerer 2000; Agrawal 2002). Finally, scholars have critiqued the entire project of "knowledge integration" by environmental scientists for upholding rather than overcoming existing power dynamics where Western modes of understanding maintain primacy. They argue that in these integration practices, Western scientists continue to lead the effort and Indigenous and community-based forms of knowledge are required to be communicated and packaged in a Western science format rather than shifting Western science to better fit within the context of other ways of knowing (Nadasdy 1999; Agrawal 2002).

Scholars and practitioners have come up with many terms to describe the knowledge, wisdom, and worldviews that Indigenous groups possess related to environmental systems, including: Indigenous Knowledge, Indigenous Science, Traditional Ecological/Environmental Knowledge (TEK), and Native Science among others (Johnson [1992] 1998; Cajete 2000; Menzies 2006; Lipe 2013; Hernandez 2022). For the purposes of this paper, we use the term Indigenous Knowledges (IKs), since it foregrounds its relation to indigenous people; it is broad and does not require the separation of environmental and cultural elements; and it is plural, signaling the multiplicity of ways different Indigenous groups relate to the world. A more detailed discussion about history, definitions, and implications of these different terms can be found in Reed (2022) and another paper in this special issue (Baldy, Begay, and Reed 2023)..

New academic frameworks have attempted to move past some of the dynamics from inter/trans disciplinary and knowledge integration approaches. The concept of "civic science" highlights doing academic work in partnership with community, weaving together "science, story, and community" (The Land Institute 2023). Additionally, the notion of "convergent science" aims to address the need for a more coherent and integrated approach to hazard risk reduction. Peek et al. (2020:2) defined convergent science as:

> [a]n approach to knowledge production and action that involves diverse teams working together in novel ways—transcending disciplinary and organizational boundaries—to address vexing social, economic, environmental, and technical challenges in an effort to reduce disaster losses and promote collective well-being.

Many of these academic frameworks, while doing much to move environmental research in more holistic and just directions, tend to present their ideas as wholly new, when in fact Indigenous worldviews and knowledges are based upon the seamless incorporation of social, cultural, ethical, and environmental elements. When thinking about a vision for SLR work at Cal Poly Humboldt, we sought an approach that could acknowledge Indigenous practitioners as the true leaders in holistic environmental stewardship. We also sought an approach that confronts entrenched power dynamics and forefronts Indigenous knowledges and leadership, while also acknowledging the important contributions that academic and scientific knowledge can bring to understanding and addressing SLR.

We have chosen to draw inspiration from the allegory of the braid as described by Robin Wall Kimmerer (2013) in her seminal work *Braiding Sweetgrass*. In the book she describes how, in braiding sweetgrass, individual "strands once separated are rewoven into a new whole" (Kimmerer 2013:256). This allegory might extend locally to processes of weaving with plant materials to create baskets, regalia, and other cultural items. Weaving remains an important part of the culture of many California North Coast Tribes including the Wiyot Tribe (CIBA 2022). Indigenous weavers in this region utilize materials from many local plants including spruce root, willow, alder, hazel, beargrass, and ferns (Landry, personal communication 2022). The notion of braiding or weaving could also provide a useful framework for how Cal Poly Humboldt might move forward to fully realize its potential as an institution to address climate issues like SLR. We at the SLRI envision building a space where different strands of thinking—whether they be different ways of knowing or academic disciplines—can be woven or braided together to create a strengthened, holistic, and inclusive approach.

This paper begins with some background information about SLR in Wigi and the North Coast region, then through separate sections, describes the approaches from five of the many different strands or ways of thinking connected to SLR concerns in the region: Indigenous Knowledges and Leadership; Geosciences; Marine and Coastal Science; Engineering; and Social Science, Policy, Law, and Planning. Finally, we describe the work of braiding those strands together into a more holistic vision for equitable, resilient, and transformative SLR practice. We also present a set of suggestions for how Cal Poly Humboldt, with many partners, can grow and develop to take on the responsibility of becoming a leader in SLR, climate, and community resilience work.

Sea-Level Rise and the California North Coast Region

The California North Coast region—defined roughly as the coastal areas in Mendocino, Humboldt, and Del Norte counties—is remote, lower-income, and less developed than the more urban coastline in both Southern California and around the Bay Area. There is a strong Tribal presence in the region; over a dozen Tribal Nations and Tribal organizations have citizens whose ancestral territory includes the coastline of the North Coast. The region is home to three major ports and numerous coastal communities. As the only major academic institution in the region, Cal Poly Humboldt has the responsibility to support and collaborate with Tribes and communities throughout this region as they face SLR.

Situated in the middle of the region is Wigi. Given that Wigi is experiencing the fastest rate of SLR in California, much of the initial SLR work has focused there. The Wiyot People have occupied the lands surrounding Wigi since time immemorial. Prior to settler arrival, the Wiyot "occupied a string of villages that encircled" Wigi. Many of these village sites were in coastal wetlands and the Wiyot people used the bay for sustenance, travel, and cultural practices (Rohde 2020:22). White settlement was devastating to the Wiyot people, notably through a series of massacres in 1860 which reduced the population from 1,500-2,000 to just 100 by 1910 (Wiyot Tribe 2022). Despite this devastation, the Wiyot people have continued to occupy this region and maintain their cultural worldviews. Descendants of the Wiyot People are members of several present-day Tribal Nations including the Wiyot Tribe, Bear River Band of the Rohnerville Rancheria, Blue Lake Rancheria, and Trinidad Rancheria. The Wiyot Tribe alone is now over 600 members strong. The Wiyot Tribe states that, "Wiyot culture remains living and dynamic to this day" and the Tribe's Cultural Heritage Center recognizes "culture as a dynamic process and the Wiyot as a living people." The Heritage Center maintains a goal to "treasure the past, enrich the present, and meet the challenges of the future" (Wiyot Tribe 2022).

In many ways, this colonial history has set the stage for the SLR issues Wigi now faces. In addition to the devastation that white settlement left on Indigenous inhabitants of the region, the settlement period also contributed significant alterations to the Wigi landscape. In order to create grazing and agricultural lands, settlers built a series of dikes and levees around the shores of Wigi (Rohde 2020). These engineered shorelines cut off coastal wetlands from the bay and resulted in the loss of nearly 90% of the bay's saltwater wetlands and marshes (Barnhart, Boyd, and Pequegnat 1992). The legacy of this modification created the conditions for the SLR and flooding challenges facing all communities around Wigi today. A 2013 inventory shows that 75% of Wigi's shoreline is artificial, much of which is decaying and at risk of breaching (Laird, Powell, and Anderson 2013; Laird and Powell 2020). The parts of Wigi projected to be inundated with SLR overlap with the historic location of salt marsh habitat; meaning that SLR, without intervention, could return Wigi close to its pre-colonization size. Figure 1 shows maps of the historic salt marsh (a) and projected areas for inundation with 0.5 and 1.0 meters of SLR (b).

Since the construction of the artificial shoreline, critical infrastructure was developed and now exists in flood-prone areas. Rising seas will need to be met by substantial restoration, adaptation, and/or relocation to avoid the disruption of services and to regain ecological functioning of historic salt marsh areas. The Wigi shoreline is governed by a patchwork of Tribal, city, county, state, federal and regional government entities, all of whom will need to coordinate for effective adaptation (Humboldt County 2018).

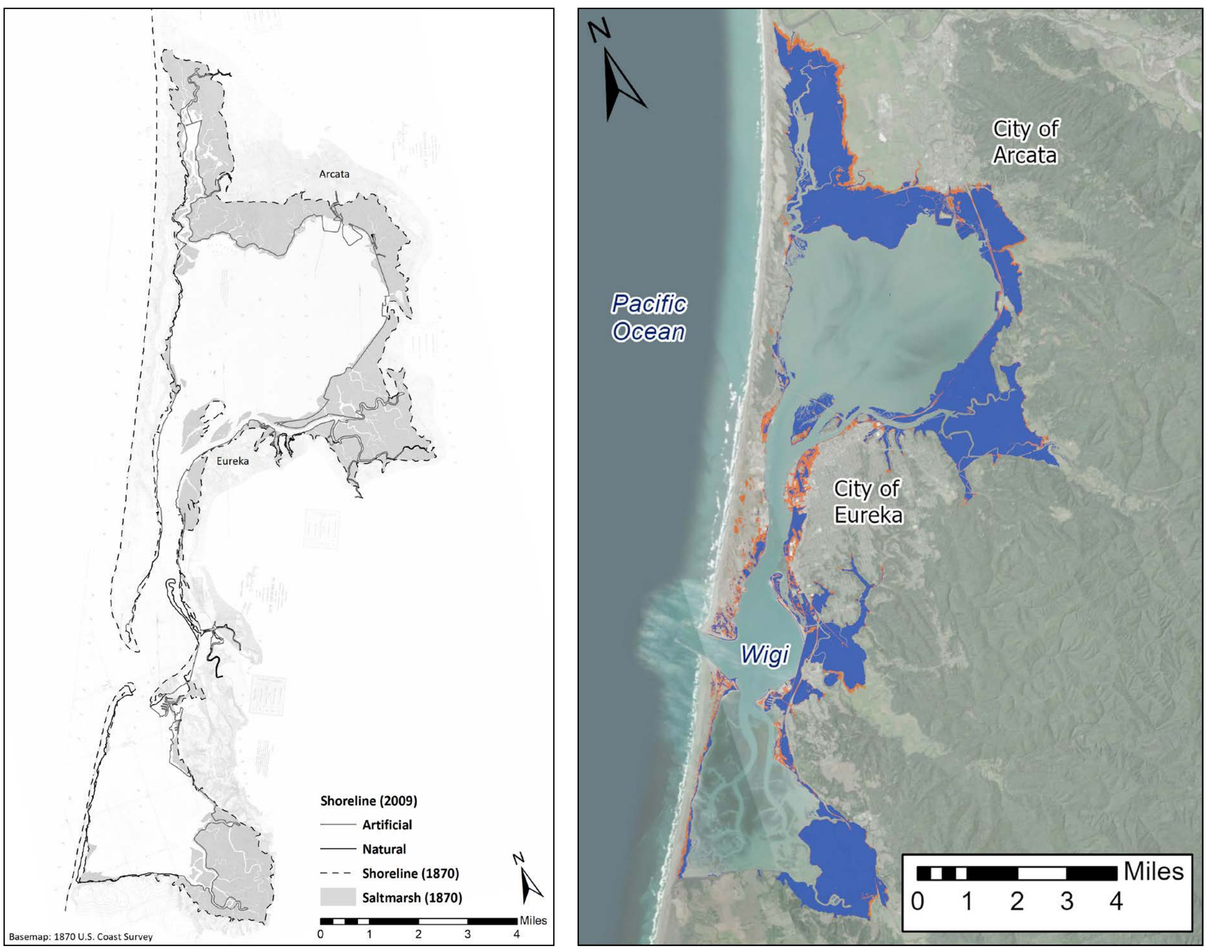

Figure 1: (a) 1870 USGS survey of Wigi, with 1870 shoreline (dotted line) and 2009 shoreline (thin line for artificial and thicker line for natural), serves to illustrate the historic size of the bay (current bay size plus the historic saltmarsh areas in gray) and the magnitude of change to the bay following white settlement. Map: Jay Patton based on data from Laird et al. 2013. (b) Map showing inundation areas with 0.5 m (1.6 feet—projected for 2040) (in the darker blue) and 1.0 meters (3.2 feet—projected for 2065) (in the lighter orange) of relative sea-level rise (Map: Kristen Orth-Gordinier).

Researchers have discovered that at the same time the level of the ocean is rising, the land around Wigi is subsiding, leading to stark SLR projections (NHE 2014; Patton et al. 2017; Figure 1b; Table 1). Local researchers have conducted extensive SLR assessment and planning work which shows that important economic, social, and cultural assets in the Wigi region are at risk from SLR. A recent Humboldt Area Hazard Mitigation Planning effort showed that SLR is likely to affect 2,686 residents and 1,164 buildings whose structure and contents are valued at an estimated $2.3 billion (Tetra Tech 2019). A recent vulnerability assessment revealed that three low-income residential communities along Wigi (King Salmon, Fields Landing, and Fairhaven) are of such low elevation that they have been projected to start experiencing monthly flooding from SLR as early as 2030, and some areas already flood during the highest tides of the year (DWR 2019; Kunkel 2019; Laird 2019).

Table 1. California Ocean Protection Council Projections for relative sea-level rise on Humboldt Bay (Wigi) based on the high-emissions, medium-high risk aversion scenario (OPC 2018).

Year	Projected Rise (ft)	Projected Rise (m)
2030	1 foot	0.3 m
2050	2 feet	0.61 m
2060	3 feet	0.91 m
2100	7.6 feet	2.32 m

Most of the diked former tidelands surrounding Wigi are used for dairy and livestock, field and row crop, and cut flower production, and SLR is likely to reduce their agricultural value as fields become inundated with salt water (Laird 2018b). Crucial transportation and utility infrastructure including Highway 101, regional power generating, and wastewater treatment facilities will be affected (Laird 2018a). Spent nuclear fuel from the decommissioned Pacific Gas & Electric (PG&E) nuclear power plant on Wigi is at risk of being exposed through shoreline/bluff erosion if 2.0 meters of sea level rise is allowed to overtop an existing sea wall (Laird 2019; Brown and Marlow 2023). In 2018, Laird and the Wiyot Tribal Historic Preservation Office identified 52 Wiyot cultural sites likely to be affected by 1.5 meters of SLR (Laird 2018a). Further, SLR is projected to have profound ecological consequences on Wigi as it may shift the composition of coastal wetlands that are important for migratory birds on the Pacific Flyway (Laird 2018a), and rising seas could lead to the flooding of contaminated sites, causing toxins to leach into the bay (Laird 2016).

Strand 1: Indigenous Knowledges and Leadership

The colonial legacy of the United States has contributed to untold social and ecological harms. Genocide and land theft have acted to sever Indigenous connections to, and leadership in, the stewardship of lands within their ancestral territories (Gilio-Whitaker 2020; Fernández-Llamazares et al. 2021). Settler land use and management paradigms radically shifted landscapes, contributing to ecological degradation and setting the stage for the climate crisis (Reibold 2022). SLR provides a transformative opportunity to overcome colonial paradigms for environmental stewardship. This can be done by centering IKs and indigenous leadership in research, planning, implementation related to SLR.

Indigenous Knowledges

IKs are described as inherited wisdoms or bodies of observational knowledge passed down through generations and intricately woven through culture in ways that have allowed Indigenous peoples around the world to sustain themselves in dynamic environments (Cajete 2000; Kimmerer 2000; Bethel et al. 2022). IKs are gaining prominence for their ability to address complex environmental challenges; however, until recently, these ways of knowing were marginalized and often dismissed as mythology or folklore (Lipe 2013). As the original stewards of the land, Indigenous people have coevolved with environments and continued to adapt to changing climates since time immemorial and can contribute great insights to climate resilience.

There are important ethical considerations related to the use of IKs. Scholars warn that it may not be appropriate to separate insights from IKs from their cultural context (Agrawal 2002) and some aspects of IKs may be considered confidential (Kimmerer 2000). Therefore, Tribes and Indigenous knowledge-holders must maintain autonomy over how IKs are collected and shared. Additionally, drawing inspiration from IKs without centering the vision and leadership of the Indigenous Nations from which the knowledge comes, can be considered a form of appropriation (Smith 2021).

Drawing from IKs in climate research and practice contributes to greater understanding of material and physical landscape changes (Hernandez 2022). Further, IKs can contribute to new ethics or value insights, potentially challenging academics and practitioners to transform their worldviews and imagine new relationships with the 'more than human world' (Kimmerer 2013; Johnson and Larsen 2017). Indigenous oral accounts describe the ecological and social history of the Wigi region, including seismic events, geologic processes, ecosystem properties, shifts in land use practices, and movements of people that Western science has only recently been able to articulate—often only partially. IKs can also provide insights into technologies and techniques for adapting to SLR; as an example, the Swinomish Tribe has revived the practice of clam gardening as a technique to prevent coastal erosion and produce culturally important foods (Ryan 2022). The Wiyot Tribe, with support from the SLRI, has received three grants to develop a climate adaptation plan. As a part of this effort, Tribal staff have been conducting interviews with Tribal citizens to gain an understanding of Tribal knowledge and priorities related to SLR and climate change.

Several Indigenous practitioners state that IKs and Western science are not mutually exclusive and that braiding these understandings together can produce a strengthened approach when Indigenous leadership is centered and ethical considerations are addressed (Kimmerer 2013; Lipe 2013; Emery et al. 2014; Matson et al. 2021). Native communities in North America have been taking a leadership role in planning for climate change, often through implementing techniques that draw from Indigenous worldviews along with Western science (Jones 2020). In a genuine practice to braid these understandings in our region, we may be better positioned to approach SLR issues by filling research gaps and bolstering our collective understanding of complex changes facing our region. Local Tribes, including the Wiyot Tribe, have the potential to be innovators in terms of developing SLR resilience strategies that draw from Indigenous knowledges and worldviews. Ecocultural approaches to SLR adaptation might produce ecological and cultural benefits such as supporting habitat for species that provide culturally important foods.

Indigenous Leadership and Land Return

SLR provides the opportunity to elevate Tribes into a leadership role in the planning for the future of coastal resources within their ancestral territories. The SLRI prioritizes Tribal leadership with a Tribal co-chair and a goal to develop projects that are of priority to Tribes. Further work can be done to consider how governance structures related to SLR adaptation and planning around Wigi can codify Tribal leadership and co-management. Cultivating Tribal leadership also requires supporting capacity development among Tribes to build the expertise and personnel to address these key questions. Cal Poly Humboldt can continue to support this process through more research grants and projects that include funding to support Tribal staff time and capacity—building off the momentum from collaborative SLR projects conducted to date with the Wiyot Tribe.

SLR may also provide the opportunity to upend unjust land ownership structures. Returning culturally significant places to the original stewards is a potential SLR resilience strategy that could serve many purposes including (1) addressing historical injustices while bringing healing and empowerment to Tribes, and (2) providing the opportunity for Tribal leadership to implement strategies for adaptation that would benefit all in the region.

Tribal acquisition of coastal properties could accelerate the process to implement SLR and coastal resilience strategies, as upon acquisition, the Tribe could prioritize implementing ecocultural resilience activities. The Wiyot Tribe has already exhibited the capacity to implement such actions. In 2004 when the Tribe acquired portions of Tuluwat Island—a sacred site where toxic waste had been sitting unaddressed for over a decade—they immediately initiated a process to clean up the site which they completed in 2014 (EPA 2018). Without the Tribe's acquisition of the property and leadership on ecocultural restoration, the contaminated site would likely still sit unabated, remaining a pollution risk to all users of the bay, particularly as SLR threatens to inundate the site.

Land return also provides an opportunity for Tribes to expand land ownership as a form of resilience to SLR. For example, the Wiyot Tribe owns less than 1% of the land within their ancestral territory and many of those holdings are within low-lying coastal areas at risk of inundation from SLR. Acquisition of more upland coastal property can help the Tribe to maintain and even grow their landholdings against the threat of land loss from SLR. As an example, the SLRI has partnered with the Wiyot Tribe on a recent OPC funded project that has enabled them to purchase Mouralherwaqh, a 46-acre parcel of coastal property upland of King Salmon, for ecocultural restoration purposes.

Strand 2: Geosciences

Broadly, geoscience is the study of the earth and the processes that shape it, encompassing earth sciences such as geology, oceanography, and atmospheric science. Earth scientists use observations, data analysis, theory and modeling, and other specializations in particular methods (e.g. geospatial scientists who specialize in mapping phenomena on the earth's surface). Geosciences are crucial to understanding the cause, extent and type of impacts from SLR as well as providing a means to map, visualize, and communicate SLR impacts and processes.

Geoscience and SLR

The impact that SLR will have on any given place on the coast is tied to two factors: (1) global SLR or the extent and speed at which seas will rise as a result of climate change and other factors; and (2) the vertical motion of the land in that area or the extent to which the land is either uplifting or subsiding. If the land in a given area is subsiding (going down) at the same time that seas are rising, that can lead to greater SLR effects and conversely, if the land is uplifting, the impact from SLR may be moderated. The rate at which seas are rising in relation to the rate at which land elevation is changing is often referred to as relative sea-level rise (rSLR). Geoscientists can provide insights into both factors that influence rSLR leading to more accurate SLR projections.

Many factors can contribute to vertical land motion (VLM) including subsidence from sediment compaction (Allen 2000), ground water extraction (Ireland, Poland, and Riley 1984), glacial isostatic elevation change (Peltier 1976), and geothermal factors (Massonnet, Holzer, and Vadon 1997). However, the key contributor to VLM in this region is tectonics—namely how the Earth moves in response to interactions between various earthquake faults and tectonic plates. The tectonics of coastal Northern California are dominated by overlapping plate boundaries: the Cascadia subduction zone (CSZ), the San Andreas fault, and the Mendocino fault. The Gorda plate subducts beneath the North America plate at about 36 mm/year to form the CSZ megathrust fault (McCaffrey et al. 2007; Appendix A1). Between large earthquakes, regions directly above the CSZ fault tend to subside and regions landward of the fault tend to uplift (Hyndman and Wang 1995; Wang et al. 2001; Loveless and Meade 2010; Feng et al. 2012).

In the fall of 2010 a group of geoscientists, including individuals connected to the SLRI, formed the Humboldt Bay Vertical Reference System Working Group (HumBayVert) (Patton et al. 2017, 2023) with a goal to evaluate the tectonic contributions to local sea level in Northern California. They used tide gage data, Global Navigation Satellite System data (GNSS; the international version of GPS), and National Geodetic Survey first-order leveling data to help measure land-level change in the southern CSZ region.

This group produced estimates of annual vertical land motion and relative sea-level-rise rates for various sites throughout the California North Coast region (Table 2). Their work shows great variability in VLM across the region; Wigi is subsiding while the surrounding ar-

*Table 2. 20th to 21st Century local relative sea level (rSLR) and vertical land motion (VLM) rates for sites in Northern California.**

Tide Station	Relative Sea Level Rate (mm/yr)	Vertical Land Motion Rate (mm/yr)
Crescent City	-0.84	2.83
Trinidad	2.86	-0.87
Mad River Slough	2.53	-0.54
Samoa	3.92	-1.93
North Spit	5.20	-3.21
Fields Landing	4.65	-2.66
Hookton Slough	6.64	-4.65

*Note: rSLR rates show the rate at which the sea level is changing—negative rates mean the sea level is going down relative to the land, while positive rates mean it is rising relative to the land. VLM rates depict the rate at which the land elevation has been changing—negative rates mean the land is subsiding and positive rates mean it is uplifting. These rates have been developed through looking at past data from tide gages throughout the region and, as such, these data differ from the future projections highlighted in Table 1. Sources: Patton et al. 2023.

eas are not (Table 2; Appendix A2). South of Humboldt Bay there is uplift occurring in the Fortuna-Scotia region, similar to the uplift rates north of Wigi. Rates of VLM are estimated at -4.65 mm/year (subsidence) in Hookton Slough in southern Humboldt Bay, and 2.83 mm/year (uplift) in Crescent City (Table 2). Within the bay, the North Spit and Samoa show the lowest rates of subsidence while Hookton Slough shows the highest rates of subsidence. The rate of subsidence in south Wigi is among the highest on the entire West Coast. Figure 2 in Appendix A depicts VLM rates at the sites used in the Patton et al. (2023) analyses.

Quantifying future local sea-level change is the first step in planning strategies for coastal ecosystems (Church et al. 2011; Horton et al. 2014). Results from the Patton et al. (2023) study provides fundamental sea-level rise data for making management decisions as they apply to coastal landscapes and the species and ecosystems that are the most vulnerable to future sea-level rise (Nicholls and Cazenave 2010; Nicholls 2011). The results from the HumBayVert studies have already been incorporated into sea-level-rise planning in Humboldt County, the cities of Arcata and Eureka, and the communities of Fairhaven, Fields Landing, and King Salmon (Laird 2018). There is a need to build off this work to develop more accurate assessments in the Wigi region and beyond.

Geospatial Analyses

Geographic information science (GIS), spatial analysis, and remote sensing are concerned with the spatial distribution of features on the earth. This includes the movement of water and the resulting impact on our environment and built infrastructure. Cartography is concerned with the creation of maps that can accurately portray spatial information to diverse audiences. These disciplines and their related technologies (such as geographic positioning systems (GPS)) are part of an overall geospatial discipline that is utilized by a wide variety of other disciplines and are key to understanding existing and long-term effects of SLR.

Notable uses of geospatial sciences include work in the Historical Atlas of Humboldt Bay and Eel River Delta, developed by Aldaron Laird in 2007, and the Humboldt Bay Shoreline Inventory, Mapping, and Sea Level Rise Vulnerability Assessment (Laird et al. 2013) which include historical maps back to 1854, aerial photographs from 1948, and maps of the current conditions of the bay. The atlas documents changes in shoreline location and shoreline types around the bay and their varying levels of vulnerability. Updated maps (Anderson 2018) showing the potential areas of future inundation are available on the SLRI website (SLRI 2023).

Overall, SLR may require geoscience disciplines to transform with new types of collaborations across disciplines and sectors, including geoscientists working closely with planners and communities to find more effective ways to communicate findings to a wide audience. Additionally, SLR will require scientists to develop a more precise understanding of VLM and how it is influenced by tectonic processes.

Strand 3: Marine and Coastal Science

Around the world, rSLR in combination with other aspects of climate change is affecting the distribution and ecosystem functions of marine habitats at the same time as it is damaging infrastructure and systems that people depend upon. For example, seagrass beds in both hemispheres support a diverse biota, much of which is commercially and culturally important (Wyllie-Echeverria et al. 2002; Cullen-Unsworth et al. 2014). But as seas rise and beds move upslope to pursue sufficient light, they encounter natural and anthropogenic upland barriers and so become locally extinct when the water becomes too deep (Short and Neckles 1999, Prosser at al. 2018). In this case, ecosystem functions that humans depend upon, like making ocean water less acidic, carbon sequestration, the raising of juvenile salmonids as well as rockfish and crabs, food for birds on the Pacific Flyway, and recreation, are also lost (Duarte 2002, Mazarrasa et al. 2015).

SLR does, however, present an opportunity for a paradigm shift. Local government planning processes understandably focus on infrastructure but usually do not concomitantly include marine habitats (e.g. Humboldt County Civil Grand Jury 2022). A more effective planning process would integrate the responses for infrastructure with concern for vulnerable coastal habitats (e.g., salt marsh, eelgrass, and freshwater marshes). Pragmatic considerations, like the penetration of seawater underneath earthen dikes, and the financial costs of adding new barriers, may necessitate this approach. Marine and coastal scientists may also be able to speak to the potential environmental impacts of various SLR adaptation strategies and assist with the development of more ecologically favorable approaches.

Marine Habitats of Humboldt County

SLR has the potential to dramatically shift the region's marine and coastal habitats, particularly as they interact with artificial shoreline structures installed during the settler period and beyond. Barriers built to hold back estuarine and open coast waters (e.g. earthen dikes) have the effect of blocking access to upland spaces into which marine habitats could shift. For example, the dikes now prevent the upslope migration of salt marsh as sea level rises. With these existing or potentially higher dikes, salt marsh is being replaced by mid intertidal mudflats, which will be replaced by low intertidal eelgrass beds, which in turn will be lost as the water deepens (Figure 2). Similar to the rSLR habitat dynamics within Wigi, if the rate of sand accumulation on the coastal beaches and

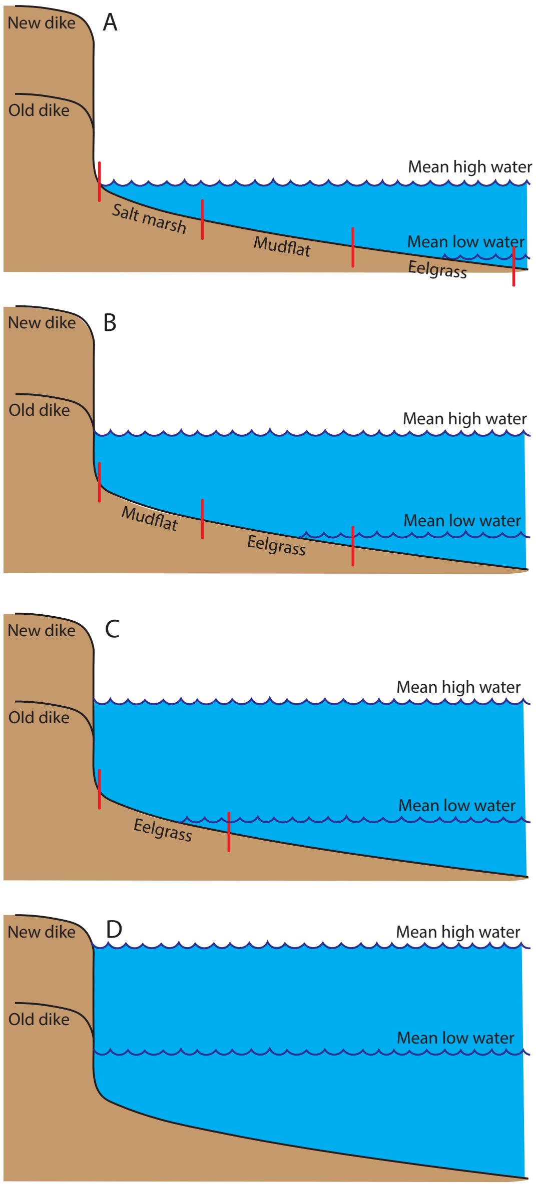

Figure 2: The chronological drowning of marine habitats in Wigi as they encounter an upland barrier during rSLR (illustration by Fiona Shaughnessy).

dunes of Humboldt County does not at least keep pace with global SLR and the downward tectonic movement of the land, then the present locations of these habitats will be overswept. Whether or not they relocate landward will depend on the extent of upland barriers. Most of the migratory and resident birds (e.g., brant goose, western snowy plover), fishes (e.g., coho salmon, black rockfish), invertebrates (e.g., Dungeness crab, clams) and marine mammals (e.g. harbor seals) that have fidelity to one or more of these estuarine or outer coast habitats would experience population crashes.

Although estimates of the global SLR rate continue to increase, the predictions of temporary *increases* of habitat size for some marine habitats in Wigi could result in planning complacency. For example, the spatial extent of eelgrass in southern Wigi is predicted to slightly increase under present day SLR conditions, or dramatically, but temporarily, increase if global SLR rates become greater than 2.8 mm/yr (Shaughnessy et al. 2012). But the only reason that eelgrass area is predicted to increase is because the size of the mudflats in Humboldt Bay happen to be greater than the size of the present day lower intertidal eelgrass beds. In other local estuaries, mudflat area could be less than eelgrass area, in which case future eelgrass area extent would immediately *decrease* in response to rSLR. Regardless of whether rSLR results in the increase or decrease in the extent of any of the intertidal marine habitats over the next several decades, they will all ultimately be lost if upland barriers are too pervasive (Figure 2).

Marine and coastal scientists have much to contribute to planning conversations related to SLR on Wigi and beyond—particularly in making sure that coastal ecosystem impacts are a key consideration in adaptation strategies. SLR provides the opportunity to remove some of the artificial barriers around Wigi to allow for the migration and restoration of eelgrass, mudflat and saltmarsh habitats. This is already happening in several salt marsh restoration projects, including the McDaniel Slough, White Slough, and Elk River Estuary projects, but a more bay-wide approach could seriously forefront ecosystem sustainability.

There are a series of research questions listed in Appendix B that flow directly from this need to more specifically understand how rSLR continues to affect local marine habitats. These questions show that input from a wide range of marine science disciplines—from the physical to the biological—will be necessary for proposing adaptation strategies that maintain marine habitats and ecosystem functions.

Strand 4: Engineering

Engineering will play a crucial role in understanding the potential impacts of climate change and developing effective adaptation strategies.

Understanding and Predicting the Effects of SLR

Engineers, along with scientists, are involved in the prediction of where and how flooding will occur from SLR. Some of the foundational models and assessments related to potential SLR impacts in Wigi were developed by engineers (e.g. Anderson 2015, 2018). In addition to quantifying the expected change in sea level, engineers can estimate the flows of sediment into and out of Wigi, and make predictions about how these flows might change under SLR. This information will inform management strategies to protect the coastal communities around Wigi. For example, Curtis et al. (2021) found that sediment supply to Wigi is projected to increase up to 58% under climate change scenarios, which could provide an opportunity to use marsh ecosystem restoration to enhance coastal protections.

Engineers can also help to understand how SLR will interact with groundwater. Research shows that in many areas, higher sea levels will push up the water table, causing saltwater intrusion into groundwater sources and leading to flooding that bubbles up from underneath the ground (Rotzoll and Fletcher 2013; Pierre-Louis 2021). This means that even if certain areas build up levees or sea walls to keep rising waters out, those areas could still flood from below—calling into question the usefulness of those protection measures. We expect SLR will increase the groundwater level in the areas around Wigi, and groundwater models developed by engineers are essential to understanding these impacts (e.g. Willis 2014). Additional research into aquifer properties would build upon these results to better understand the impacts of SLR in the surrounding groundwater systems.

SLR can affect water quality as well. Numerous low-lying contaminated sites around Wigi are vulnerable to rising sea level and groundwater. Many are former lumber mills that used a wood preservative containing dioxins, while others are former rail yards, boat repair facilities, and other industrial sites contaminated with various pollutants. Rising groundwater can flood these sites from below, pushing contaminants to the surface (May et al. 2020). Mobilizing dioxins, metals, petroleum hydrocarbons, and other industrial contaminants can impact adjacent waterways and expose people as well as wildlife, including commercial, subsistence, and sport fisheries. Engineers can help to identify toxic sites most at risk of inundation and develop effective remediation strategies.

Designing Effective and Resilient Adaptation Strategies

Conventional engineering designs to prevent flooding often focus on hard structures such as sea walls, stream channelization, levees, and riprap. However, these designs often transfer or propagate environmental vulnerabilities (Dugan et al. 2011). Nature-based designs incorporate ecosystem restoration as a strategy to prevent flooding (Pearce 2022). A recent California technical report sought to define and categorize these approaches using the term "natural shoreline infrastructure" defined as "using natural ecological systems or processes to reduce vulnerability to climate change related hazards while increasing the long-term adaptive capacity of coastal areas by perpetuating or restoring ecosystem services'' (Newkirk et al. 2018:5). Examples include: vegetated dunes, cobble berms, marsh sills, tidal benches, native oyster reef, and eelgrass beds. Research shows that in addition to having fewer negative environmental impacts, those designs may be more cost effective and provide better flood protection in the long term (Newkirk et al. 2018). Narayan et al. (2016) found that salt marshes can be particularly effective at reducing wave heights, so protecting and expanding these native ecosystems could be an important part of SLR adaptation in Wigi. The majority of protection infrastructure that is currently in place along the coastline rely on conventional hard structures with very few projects that integrate nature-based systems implemented or even studied. This provides an opportunity for Cal Poly Humboldt to play a meaningful role in developing and understanding these new (old) technologies.

Some practitioners have taken to describing SLR protection measures as falling along a spectrum from "gray" to "green," with gray being engineered hard structures and green being entirely nature-based solutions. Hybrid protection measures could fall somewhere in the middle of that spectrum. For example, a levee could be designed with a living shoreline of restored marsh or oyster reef in front of it. Engineers can assess the vulnerabilities of infrastructure to the impacts of SLR and determine what types of infrastructure improvements and protections would be most effective in specific locations. One important example is the stretch of Highway 101 that runs along the east side of Wigi. This is particularly vulnerable to SLR, and Caltrans is considering a number of engineering design solutions that would help to protect this transportation link from frequent flooding (e.g. Burns 2021; Vanderheiden 2022). Caltrans has reached out to the Cal Poly Humboldt Environmental Resources Engineering (ERE) department to develop SLR-related projects, and the fall 2022 capstone projects focused on creating road protection designs that are adaptive to SLR and fish passage. A list of potential areas or topics for continued research can be found in Appendix B.

Complex environmental challenges like SLR have contributed to transformations in fundamental thinking and modes of operating in the field of engineering. Engineering has traditionally been a field that prides itself on expertise and the ability to design and engineer out of problems, like developing sea walls, gates, and levees to prevent flooding. In SLR and flood management, some of that thinking has begun to change. Engineers are questioning hard flood protection measures designed to 'hold the line' and have begun exploring nature-based solutions and other mechanisms that gracefully let water in (Kimmelman and Haner 2017). The field has also been grappling with questions of equity, with a sense that engineers could better work with communities to co-develop design solutions. This has brought a sense of humility to the field and an openness to collaborating across disciplines and ways of knowing. IKs serve as an inspiring example as Tribes have been at the forefront of implementing forms of natural shoreline infrastructure that draw from a cultural perspective (Jones 2020).

Cal Poly Humboldt is positioned to become a leader in community and Indigenous-centered engineering with the launch of the innovative Master's Degree in Engineering & Community Practice which includes a combination of coursework in engineering and Native American studies and has students working on projects with partners from underserved communities including local Tribes. In addition, the Cal Poly Humboldt ERE department has long been a leader in nature-based designs and solutions to complex challenges—most prominently in their work to support the design and creation of the Arcata Wastewater Treatment Facility (WWTF). The unique WWTF, located at the north end of Wigi, relies on a series of constructed wetlands to treat wastewater from Arcata before releasing the cleaned water into the bay. It is listed as one of 17 case studies of wetland treatment systems in the EPA's guidance (EPA 1993).

Strand 5: Social Science, Policy, Law, and Planning

Numerous individuals, communities, and Tribes in the North Coast region will be affected by projected SLR and have a stake in the outcome of SLR planning. This highlights the importance of understanding the socioeconomic context surrounding SLR locally and seeking to develop policy, legal, and planning responses that can help to facilitate equitable, resilient, and transformative SLR adaptation.

Social Science

Scholars emphasize the importance of gaining rich, contextual information about the social conditions in communities facing coastal hazards like SLR in order to understand the potential implications of various strategies and to inform the development of effective and just adaptation actions that respond to the realities being experienced on the ground (Marino 2018b; McAdam 2011; Bettini 2013; Marino 2015; Farbotko and Lazrus 2012; Perumal 2018). Past social science research suggests that SLR adaptation processes are likely to produce inequitable outcomes without anticipatory planning and decision-making that explicitly acknowledges and seeks to overcome inequalities (Siders and Ajibade 2021; Marino 2018a,b; Hardy et al. 2017; Boyer and Penn 2013; Herreros-Cantis et al. 2020).

Sea-level rise provides a transformative opportunity for researchers to develop social science in coordination with communities and local governments that directly speaks to local SLR planning processes. Relevant research areas include: exploring the sociocultural context of coastal communities and their sense of place; documenting local knowledge, values, and priorities related to SLR; and understanding social dynamics related to coastal governance. Various researchers from Cal Poly Humboldt have engaged these issues by pursuing collaborative research projects with community partners, several of which have directly contributed to local government processes (e.g. Blakeney et al. 2011; Kunkel 2019; Carrasco et al. 2021; Orth-Gordinier 2022; Brown and Marlow 2023).

Planning

The field of coastal planning has been undergoing transformations over the past decade in response to the challenges from increased coastal hazards and SLR, as well as calls for more inclusive and just approaches (Swanson 2021; APA 2023). In the past, planners have approached challenges from coastal flooding by increasing protection measures such as dikes and levees and ensuring that home and business owners had access to flood insurance to protect those assets. While the goal of these strategies was to increase safety, paradoxically, these efforts made those areas less safe as they allowed for the development of more infrastructure in risky areas, leading to more devastation following flood and hazard events (Burby 2006). As a result, planners have moved toward considering approaches that prevent development in flood prone areas and incentivize the relocation of infrastructure and homes from flood vulnerable areas through a process sometimes referred to as "strategic retreat" (Flavelle 2020). Strategic or managed retreat programs mark a turning point, orienting away from reactive programs (such as the National Flood Insurance Program (NFIP), which provides payouts to home and business owners to rebuild their homes after a flood has occurred) toward encouraging more proactive approaches to SLR and coastal flood management. The outcomes of managed retreat programs vary widely, depending on their approaches. Efforts that aim to solely minimize physical risk (e.g., a "techno-managerial" approach), are less likely to center justice at the various scales needed to produce structural change and "transformative" outcomes (Ajibade et al. 2022).

Local governments and Tribes in the Wigi region have begun efforts to consider and plan for future SLR (see the SLRI Library Database for links to local reports and plans), but there remains a need to expand and coordinate these planning efforts locally and in the North Coast region. Planners will need to consider an array of adaptation strategies, such as developing sea walls or living shorelines; designing accommodation measures such as causeways; or abandoning inundation zones to retreat inland. Complex and potentially conflict-engendering decisions will need to be made about which areas to protect (and how) and which areas to retreat from (and when). The term 'retreat' has been controversial in SLR discussions in many parts of the world, as residents with attachments to the places where they live may interpret "retreat" as a form of "giving up" (Anderson 2022). Equity considerations arise as well, since basing decisions about retreat solely on economic factors (i.e. protecting places of the highest real estate value and retreating from others) can serve to further marginalize low income communities and exacerbate inequalities (Marino 2018a,b; Siders and Ajibade 2021).

SLR adaptation measures have the opportunity to reshape development and will have significant implications for all connected to the North Coast region. The work and practice involved with ensuring that decision-making processes are inclusive and equitable will require meaningful efforts to educate and engage the community on the issue. Such tasks will require strategic investment and innovation in community outreach and engagement, beginning with Indigenous communities. Wigi can gain inspiration from long-term water education initiatives such as the Water Leaders Institute (WLI) in New Orleans that offer creative and art-centered approaches to community learning (WLI 2022). For these reasons, some planners have argued that 40-50% of budgets for climate adaptation projects should go toward "environmental education and community-based planning processes" (Chang 2018).

Law and Policy

Climate change and SLR present novel challenges to conventional policy and legal approaches to environmental change. SLR sits precariously at the nexus of local, state, and federal authorities, with limited federal and international frameworks to guide a coordinated approach. Under the California Coastal Act, for example, SLR planning and implementation authority is shared by local and state governments, with Tribal governments in a "consultation role" (see, e.g. California Coastal Commission 2018). City and county governments prepare local coastal programs, which, upon approval by the California Coastal Commission (CCC), guide the issuance of Coastal Development Permits (CDP) in the region. However, the CCC retains permitting authority and the ability to hear appeals over certain coastal lands. The CCC retains jurisdiction over a large amount of land on the Wigi shores, which can lead to planning paralysis in SLR vulnerable areas, as neither the local government nor the state entities nor the Tribal governments are certain who should lead the effort (Laird 2018c). This complex regulatory framework evokes traditional environmental law tensions over how local and Tribal governments—those with specific knowledge and expertise over their territories, not to mention sovereignty—exercise agency over localized yet transboundary problems such as SLR (e.g. Fox 2020).

Emerging legal research is examining such tensions and asking novel questions, such as how to characterize the public trust doctrine's jurisdiction over tidelands as they migrate landward due to sea level rise, thus altering the boundaries formerly used to demarcate where public lands end and private lands begin (Lester 2021). The interaction between SLR adaptation processes and traditionally governing environmental laws and regulations remains a critical topic for the evolution of law in a climate-changed world. Other legal questions engaging this tension include how to streamline permitting processes to ensure that SLR mitigation projects can be completed on time to provide flood and other protections, while not subordinating robust public engagement and collaborative planning—as required by the National Environmental Policy Act and the California Environmental Quality Act—to urgent timelines (e.g., BRRIT 2022; CNRA 2022; Ajibade 2022).

The state of California is turning toward these questions as a national leader in establishing a bold climate policy agenda that frames climate change as a present issue rather than a distant future (e.g., the $54 billion climate action plan in Newsom 2022). California has also become an incubator of SLR policy and legislation. State adaptation strategies and policy proposals are beginning to prioritize investment in low-income communities, Tribal communities, communities of color, and communities most marginalized by poverty and climate impacts. The California Ocean Protection Council's Strategic Plan (OPC 2020), Equity Plan (OPC 2022), Tribal Engagement Strategy (OPC 2023), and SLR Guidance reports (OPC 2018) each include recommendations related to equitable SLR adaptation. For example, OPC's Equity Plan states that one of its goals is to "[a]dvance equity across ocean and coastal policies and actions" (see OPC 2022, Goal 2:19). California has also implemented Governor Gavin Newsom's Nature Based Solutions Executive Order N-82-20 (2020), which commits the state to the goal of conserving 30 percent of lands and coastal waters by 2030 (30x30). A specific initiative of 30x30 proposals in California is to provide $100 million in funding to help "implement tribal priorities including ancestral land access, co-management, conservation and return of tribal lands" (Newsom 2022).

In 2021 alone, the California state legislature considered over 12 bills directly related to SLR (California Coastal Commission 2021), including Senate Bill 1078, which proposed a novel strategy for proactive managed retreat through the creation of a Sea Level Rise Revolving Loan Pilot Program providing loans to local governments to support voluntary retreat efforts (the bill was vetoed by Governor Newsom September 29, 2022). Assembly Bill 1384, the Resiliency Through Adaptation, Economic Vitality, and Equity Act, adopted in September 2022, directs the Natural Resource Agency to work with the Office of Planning and Research (OPR) to identify vulnerabilities to communities disproportionately impacted by climate change, and coordinate state budgets to address these impacts, among other responsibilities. Whether transformative structural change will emanate from California's recent legislative and policy initiatives is an open question, but recent actions at least signal that the state seeks forward momentum in this direction.

The Cal Poly Humboldt SLRI can play a leading role in tracking California SLR law and policy development and assessing its effectiveness at facilitating equitable, resilient, and transformative change. The SLRI can provide recommendations and guidance for how existing and future laws and regulations can fund and support integrated and just SLR adaptation that enhances the resilience of the North Coast region and beyond.

Discussion

Sea-level rise transcends all kinds of boundaries—political, disciplinary, organizational, ecological, and ways of knowing. It can only begin to be understood and addressed if different disciplines and types of knowledge are brought together. Each approach and discipline brings an important lens to the table. Even as we were writing individual disciplinary sections in this paper, we found it difficult as lines between the approaches were blurry and uncertain. For example, the questions related to the hydrologic implications of SLR can be explored by engineers, geologists, oceanographers and watershed scientists. Considerations around the design of natural shoreline infrastructure draw from engineering, but also IKs and marine and coastal ecosystem science as many of those designs involve restoring coastal ecosystem habitats. Robust planning and policy incorporates knowledge and information from all fields and perspectives.

In this context, Indigenous worldviews can continue to be a source of inspiration. Lipe (2013) describes IKs as 'high context' ways of knowing, where "knowledge is gained through the understanding of many different variables at many different levels simultaneously" (Cajete 2008). With Kimmerer's analogy of the braid, we can envision these different approaches or strands winding together and, in the winding, shaping and influencing one another until neither the individual disciplines nor the overall approach remain the same. Also, braided or woven materials are much stronger than individual strands.

The SLRI was founded to provide a space for braiding these different ways of knowing. To do this we have sought to create a network that transcends disciplinary and organizational boundaries. The governance structure requires two co-chairs, one who approaches SLR issues from Cal Poly Humboldt's academic sphere, and the other from a Tribal or community position. In building SLR projects and research, we seek to listen to and address Tribal and community needs, rather than solely focusing on theoretical concepts of interest to specific disciplines. We are flexible to develop leadership and funding structures most suitable to individual projects. For many projects, Tribal, community, or local government entities are suited to lead the effort while Cal Poly Humboldt plays a supporting role. In some projects, it may make sense for private consulting firms to play a large role in developing project outputs. A strong network allows all the participants to call upon one another as expertise and resources are needed. We seek to ensure that projects are not duplicative and build upon one another. We also strive to keep students at the center of the network's operation and activities to provide learning opportunities and to gain inspiration from students' insights and perspectives.

Further developing a focus on climate and SLR resilience will help Cal Poly Humboldt achieve its vision as a "comprehensive polytechnic university for the 21st-century" that meets "workforce needs of our region and state" (HSU 2021). This will require developing disciplinary expertise as well as prioritizing avenues for bringing diverse perspectives together. SLRI members have identified the need to prioritize adding faculty expertise related to engineering, geoscience, and marine and coastal ecology aspects of SLR. In collaboration with Tribes and the Native American Studies Department, the institution can further develop expertise and educational programs related to IKs and food sovereignty and integrate these concepts into teaching and research. This could also include developing residency programs to sponsor Indigenous and local knowledge holders to bring their visions to campus.

SLRI faculty have already played a leading role in integrating SLR concepts into curriculum across the campus, including sponsoring capstone projects in Environmental Science and Management, Engineering, and Geospatial Science, where students explore and address SLR issues of interest to the local community. The SLRI includes funded positions for student researchers to engage in SLR activities. Going forward, Cal Poly Humboldt could expand upon these efforts, providing more opportunities for students, particularly underrepresented and Indigenous students, to gain training related to SLR. Some of these opportunities could be facilitated through collaborations with the Indian Natural Resources, Science, and Engineering Program (INRSEP+) and Indian Teacher & Educational Personnel Program (ITEPP). Student engagement in SLR research and education will prepare them to enter the rapidly expanding climate and SLR resilience workforce.

Cal Poly Humboldt will also need to focus on developing research and teaching structures that allow for cross-disciplinary and cross-sectoral collaboration. This could include creating the space to offer SLR and climate resilience classes co-taught by individuals of different disciplines or by a combination of faculty, community, and Tribal experts. This could also include developing more collaborative research spaces that would allow engineers, scientists, IK practitioners, and community planners to work together, perhaps through the development of indoor and/or outdoor research sites that are in the community and adjacent to Wigi. Emerging master's programs in engineering & community practice, marine science, along with discussions to develop a climate resilience master's program expand the opportunities for graduate students to develop integrative thinking and innovate the field even further. Currently SLR work at Cal Poly Humboldt is concentrated in the College of Natural Resources. However, moving forward, there is a possibility for a more expansive vision across the colleges that also incorporates the liberal arts. Fields such as political science, economics, environmental studies, Native American studies, art, literature, journalism, education, history, critical race and gender studies, social work, and other academic centers on campus have a potential role to play in an expansive vision for the topic.

The SLRI has many ideas for future work to move their vision forward. One such idea would be to support the development of a pilot natural shoreline infrastructure project for Wigi as a means to test and demonstrate the efficacy of equitable, resilient, and transformative SLR adaptation solutions. Tribal knowledge and leadership could be centered in the project by incorporating IKs, supporting Tribal leadership in planning and, if possible, by pursuing implementation on Tribally-owned or acquired sites. Engineering, geosciences, marine and coastal science, environmental science and policy, Native American studies, and IKs can all contribute to the design of an infrastructure project that would be effective for SLR protection and ecoculturally beneficial. The infrastructure planning will also need to hold up principles of environmental justice as critical design criteria (e.g. de Schipper et al. 2020). Planning and policy practitioners can assist with community involvement in project planning and implementation, developing government and private industry partnerships, navigating permitting processes, and identifying equitable funding mechanisms. Such a project would require the development of strong partnerships. A project such as this could serve as a demonstration site and educational opportunity. Students could be involved in long-term management, monitoring, and adaptive management of the project.

The emerging work of the SLRI can provide a foundation for developing a vision for transformative climate research and practice. A recent example is the Reclaiming Mouralherwaqh project where the Wiyot Tribe applied for and received a $1.2 million grant from the OPC to acquire a culturally important parcel of land and develop an ecocultural restoration plan for the site. The Tribe had prioritized acquisition of forested lands within the coastal zone and identified Mouralherwaqh as a target property for acquisition. The site contains numerous culturally important plants—many of which are not found on any of the Tribe's current landholdings. Several plants are the types used in basketweaving and ceremonial regalia. The SLRI provided support for that effort when needed, following the directive and leadership from the Tribe. The parcel was acquired in July of 2022 and the Tribe now plans to develop an ecocultural restoration that incorporates cultural use, food sovereignty, water quality, watershed/forest restoration, SLR resilience, law and policy, and other areas of interest to the Wiyot Tribe. There is funding to incorporate Cal Poly Humboldt students and faculty across several different departments into the site planning.

In August 2022, the Wiyot Tribe hosted a Mouralherwaqh Coming Home Ceremony. The Ceremony included Wiyot dances; speeches from Tribal, academic, and government partners; and a shared meal of traditional foods. As academic, community, and government representatives were there with Tribal citizens and staff to witness and celebrate the Tribe's achievement, it was possible to imagine a new paradigm for academic research and education that overcomes colonial power structures. Instead of seeking to study Tribes and communities, researchers can work to support them in achieving their priorities. In the words of Hilanea Wilkinson, a young citizen of the Wiyot Tribe, this pathway can be possible if we learn to transform and "work together."

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The work and analysis in this paper stands on the shoulders of an entire community of folks who have cared for and stewarded California North Coast coastal resources from time immemorial to today. Understanding and addressing SLR has and will continue to be a whole community effort. Cal Poly Humboldt is located on the present and ancestral Homeland and unceded territory of the Wiyot people. The land that Arcata rests on is known in the Wiyot language as Goudi'ni. Past actions by local, state, and federal governments removed the Wiyot from this land and threatened to destroy them. We acknowledge the Wiyot community, their elders both past and present, as well as future generations as a statement of commitment to actions that dismantle the ongoing legacies of settler colonialism. Funding to support the organization, writing, and editing of this collaborative work was provided by the Cascadia Coastlines and Peoples Hazards Research Hub, which is supported by the National Science Foundation award NSF-2103713. The preparation of this publication was also supported by NOAA Grant # NA22OAR4170106, through NOAA's National Sea Grant College Program, U.S. Dept. of Commerce. The statements, findings, conclusions and recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the agencies or entities for whom they work or by whom they are funded.

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Appendix

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