Pedaling on Water

How Humboldt County can Collaboratively Adapt its Regional Trail System for Sea Level Rise and Encourage Sustainable Forms of Transportation

Final Report

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Executive Summary[1]

Humboldt County has made great efforts in expanding its regional trail system in recent decades, which now includes multiple trails for recreational and transportation purposes. Recent data on sea level rise projections have illuminated threats to the county's coastal infrastructure, including many of these trails. Crucial trail infrastructure projects that have already been completed or are in the planning process are going to be some of the first structures threatened as a result of sea level rise. Creating and supporting networks for active transportation will be important in reducing our greenhouse gas emissions and addressing the global climate crisis. The purpose of this report is to advocate for active transportation options and suggest recommendations for the protection and expansion of multi-use trail infrastructure within Humboldt County, which will serve as both climate adaptation and mitigation strategies.

The report begins by assessing the current threat of sea level rise on the Humboldt Bay Area Regional Trail System. The purpose of this step is to establish a time frame that decision makers can refer to when considering which areas should be prioritized initially. A literature review exploring known coastal adaptation measures including hard and soft shoreline maintenance, land raising, raised causeways and planned retreat follows. Costs and benefits associated with each measure are discussed in order to gain a better understanding of why certain measures are better suited to different communities.

In the ensuing sections, major uncertainties and common gaps in knowledge that communities around Humboldt Bay are facing when considering adaptation strategies are explored. These challenges include difficulty with assessing costs of adaptation strategies, variability of sea level rise predictions, and identifying and securing adaptation project funding. Through stakeholder analysis and interviews conducted with community leaders of trail development and sea level rise adaptation around Humboldt Bay, we learned what concerns different groups have for SLR planning in the future. A synthesis of these interviews is included to present the current positions of these community leaders, their concerns, and recommendations.

Based on the literature review, stakeholder analysis, and interview results, this report concludes with recommendations on approaches to collaboration, trail design, and transportation development moving forward. Recommendations include: institutionalizing more robust communication and collaboration, possible design and structural considerations, and finally the case for carrying current momentum and inducing demand for alternative transportation infrastructure in the region into the future.

[1] The research, analysis, and recommendations presented in this report were created by students in Humboldt State University's Environmental Science and Management Planning Practicum class in Spring 2021, at the request of Colin Fisk of the Coalition for Responsible Transportation Priorities and Jennifer Kalt of Humboldt Baykeeper.

Introduction

Humboldt County in recent decades has made important strides in expanding its regional trail system. Recent data on sea level rise (SLR) rates have revealed threats to the county's coastal infrastructure. Crucial trail infrastructure projects completed or planned, are going to be some of the first structures threatened as a result of sea level rise complications. In 2019 the transportation sector generated 29% of the United States 2019 greenhouse gas emissions (US EPA, 2019). Creating and supporting networks for active transportation will be a key component in reducing our greenhouse gas emissions and working to address the climate crisis. Active transportation is also called physical transportation because it relies on human power instead of petroleum products. This report advocates for and makes recommendations for the protection and expansion of multi-use trail infrastructure within Humboldt County.

Our group was brought to the task of categorizing the threat of sea level rise to Humboldt County's regional trail system and recommending adaptation measures by Colin Fiske of the Coalition for Responsible Transportation Priorities and Jennifer Kalt of Humboldt Baykeeper. Included in this analysis was an exploration of the expected timeframe of impacts and flooding of those trails, and different approaches to prepare for those impacts over time. Climate goals outlined by the state of California make transitioning transportation methods and reducing vehicle miles traveled a priority (California Transportation Commission, 2021). We see trail infrastructure as a vital component in the array of possible options to combat the causes of climate change and adapt to its impacts. After a brief introduction to the regional trail system, and the threat posed by SLR, we present a brief review of the literature on coastal adaptation methods. We then present the results of stakeholder analysis-based interviews with local transportation and SLR experts in the Humboldt Bay Area focused on challenges to the trail system. The report concludes with a series of recommendations for adaptation for the future. We developed a series of goals to help guide the creation of this report (Table 1).

Table 1: Project goals and desired outcomes

Project goals	Desired Outcomes of Goals
Categorize the threat of sea level rise on trails in the Humboldt County Regional Trail System.	- Aggregate sea level rise data (with respect to trails) in order to have one document that interested parties can refer to.
Explore Humboldt County's as well as different coastal communities' approaches to sea level rise adaptation.	- Assess measures under consideration for protecting Humboldt County's trails from sea level rise. - Review and assess sea level rise measures being taken elsewhere and assess their feasibility within Humboldt County.
Present and analyze stakeholders' visions for the future, as a contribution toward future collaboration.	- Gain an understanding of visions of the future of trails within Humboldt County through interviews with community stakeholders. - Foster connections between major stakeholders that will influence the future of trails in Humboldt County.
Make recommendations based on observations synthesized from the report creation process.	- Establish a clear presentation of the group's findings based on our research, interviews, and institutional knowledge, with the intent to encourage better communication among stakeholders, maximize climate adaptation and mitigation, and increase alternative transportation connectivity and longevity in the Humboldt Bay community.

1.1 Humboldt Bay Area Regional Trail System

The Humboldt Bay Area Regional Trail System (HBARTS) is a group of existing and proposed trails that traverse the Humboldt Bay Area (Figure 1). The goal of the trail system is to provide both residents and visitors with a regionally and locally connected trail network that will provide options for safe active transportation for commuting and recreational purposes. The current list of trails in the system includes the Hammond Trail, Eureka Waterfront Trail, and Humboldt Bay Trail North, among others. All of these trails are part of the California Coastal Trail and Pacific Coast Bike Route as well. The list of proposed trails includes extensions and modifications of existing trails as well as the construction of some new trails.

Fragmented jurisdictions between different sections of the system make planning for its future more complex. For example, the Hammond Trail is under the jurisdiction of Humboldt County and the California Coastal Conservancy. The Eureka Waterfront Trail is under the jurisdiction of the City of Eureka, and the Humboldt Bay Trail North is under the jurisdiction of the City of Arcata with initial funding provided by the California Coastal Conservancy. The proposed Humboldt Bay Trail South project that will complete the connection between Eureka

and Arcata falls under Humboldt County's jurisdiction (Figure 2). Drafting future plans for these trails that will satisfy every agency, as well as all other stakeholders, is a difficult task.

The Humboldt Bay Trail has been in the works for two decades and will likely take several more years to complete. Once completed, this continuous 14-mile non-motorized trail will establish active transportation connectivity between Eureka and Arcata while improving road safety and protecting transportation infrastructure from the short-term impacts of sea level rise. The final trail section between Eureka and Arcata (Humboldt Bay Trail South (Figure 3)) will act as both a sea level rise adaptation measure and work to mitigate future SLR. Without this final section of trail, the highway would face a high risk of inundation (Figure 4). While initially conceived for transportation and recreation, the physical presence of the built-up rail prism adjacent to the trail will buffer it from anticipated rising seas for a time (Figure 5). The active transportation corridor will encourage people to drive their cars less, which reduces greenhouse gas emissions (Ludwiszewski & Haake, 2008).

Sea level rise is already beginning to impact coastal communities across the world. Due to the plate tectonics in this area (see Appendix A), Humboldt Bay is experiencing the fastest rate of sea level rise on the West Coast of the United States (Laird, 2013). The combination of land subsidence and rising sea levels is expected to result in at least one foot of sea level rise by 2030. In addition, about ¾ of the shoreline around Humboldt Bay is artificial, 50% of which is man-made dikes from the 1800s (Laird, 2013). Due to the history of diking salt marsh habitat and developing in flood zones, the cities of Eureka and Arcata face complex challenges in adapting to future sea level rise.

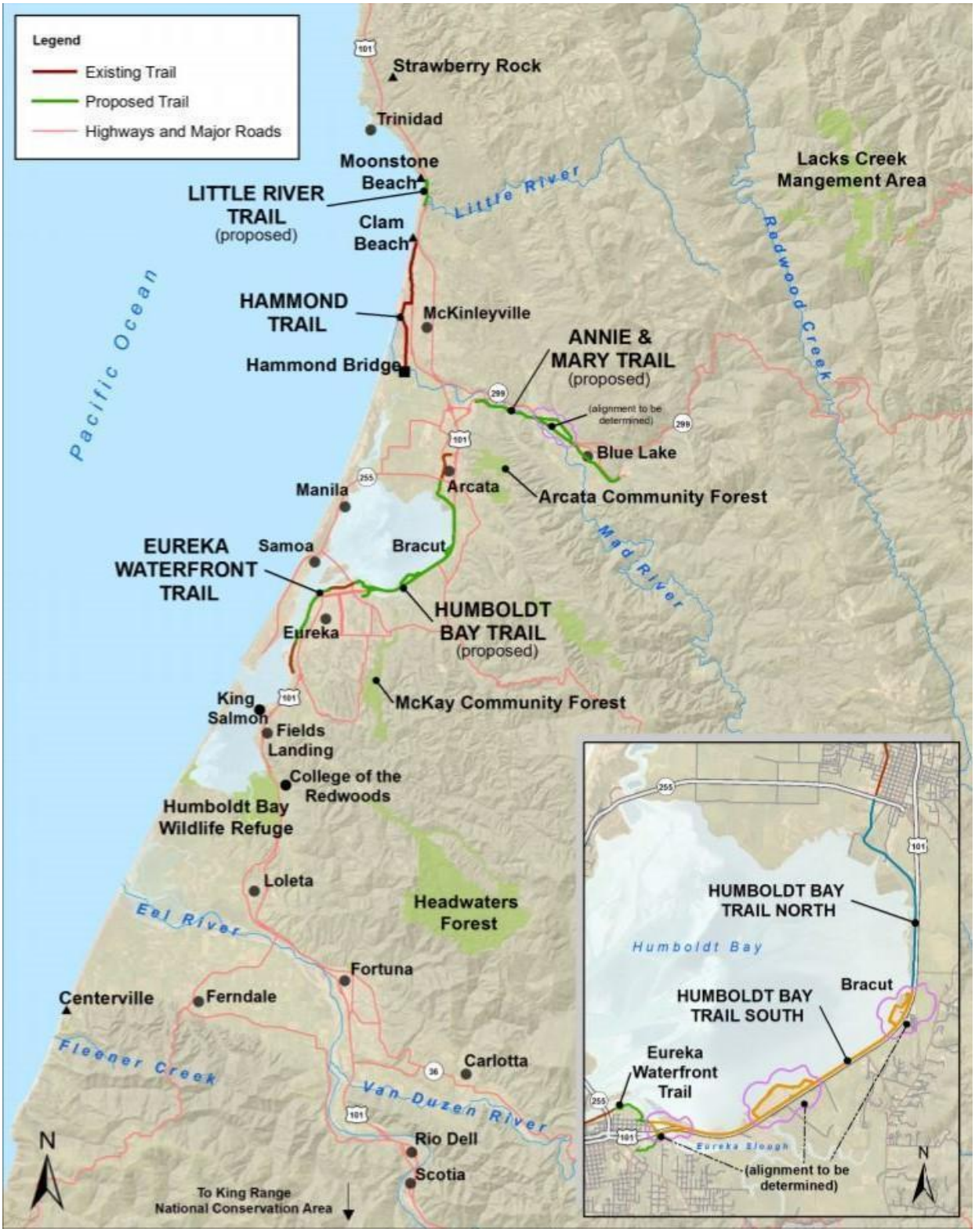

Figure 1: The state of HBARTS as of 2016. The Eureka Waterfront Trail and Humboldt Bay Trail North have since been completed. See Appendix B for a locator map of Humboldt Bay. Source: County of Humboldt (2016)

Figure 2: Map of Humboldt Bay Trail completed and proposed segments to date. Source: County of Humboldt (2017)

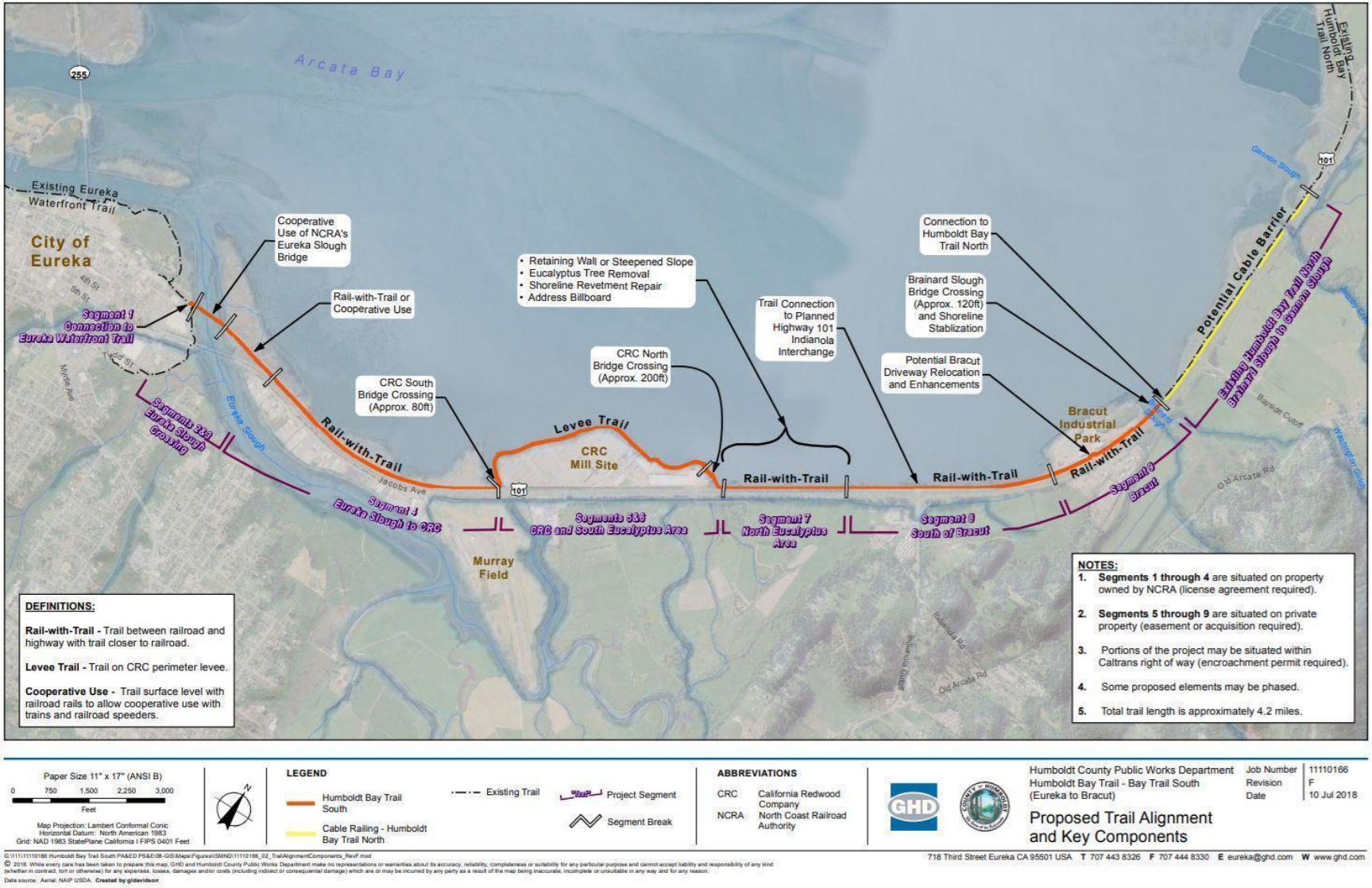

Figure 3: Segments of the final Humboldt Bay Trail South section between Eureka and Arcata. Source: GHD (2018)

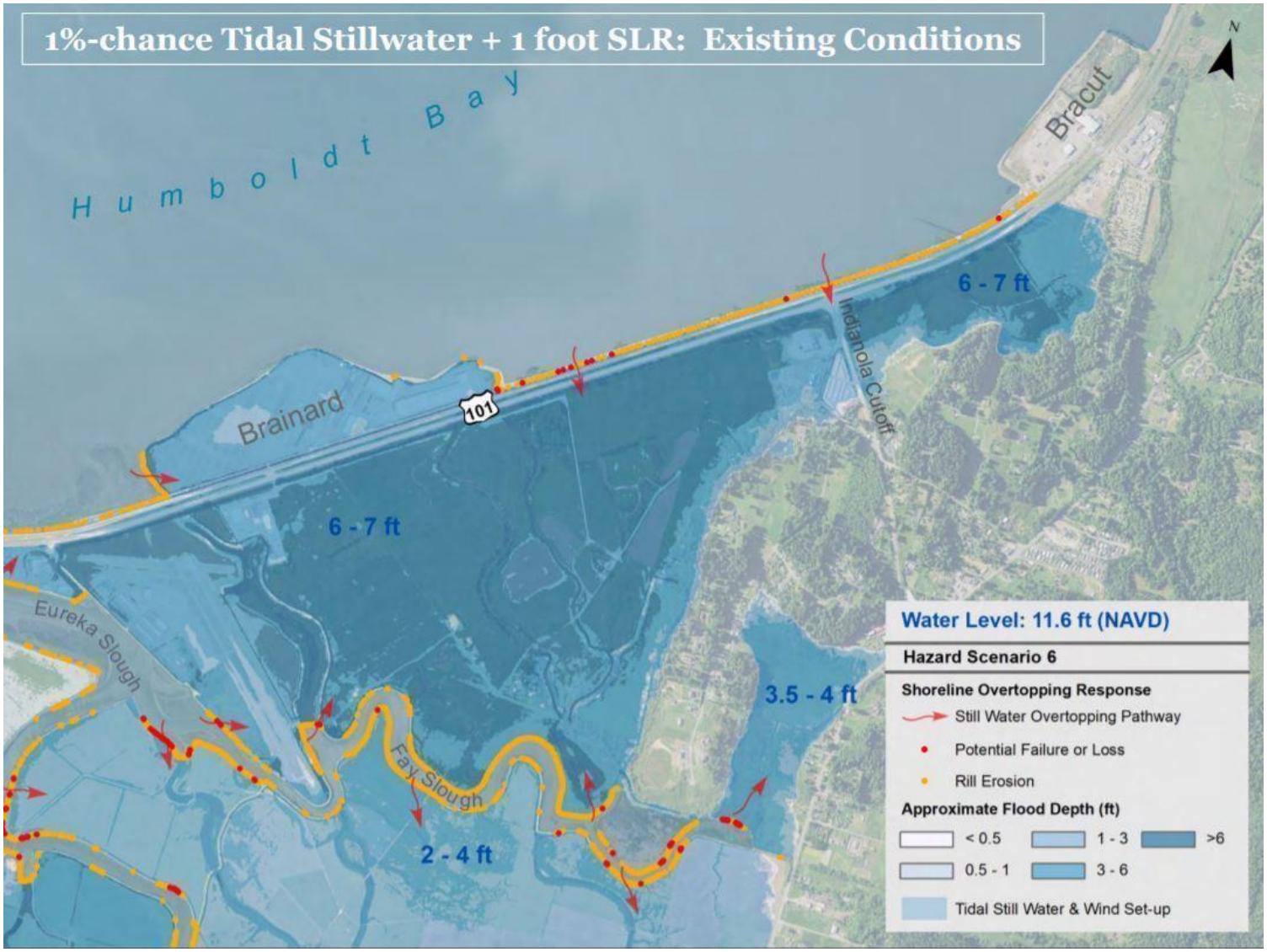

Figure 4: Flood area for 1% chance storm event combined with 1 foot of sea level rise on the 101 Highway corridor between Eureka and Arcata. Source: GHD (2021)

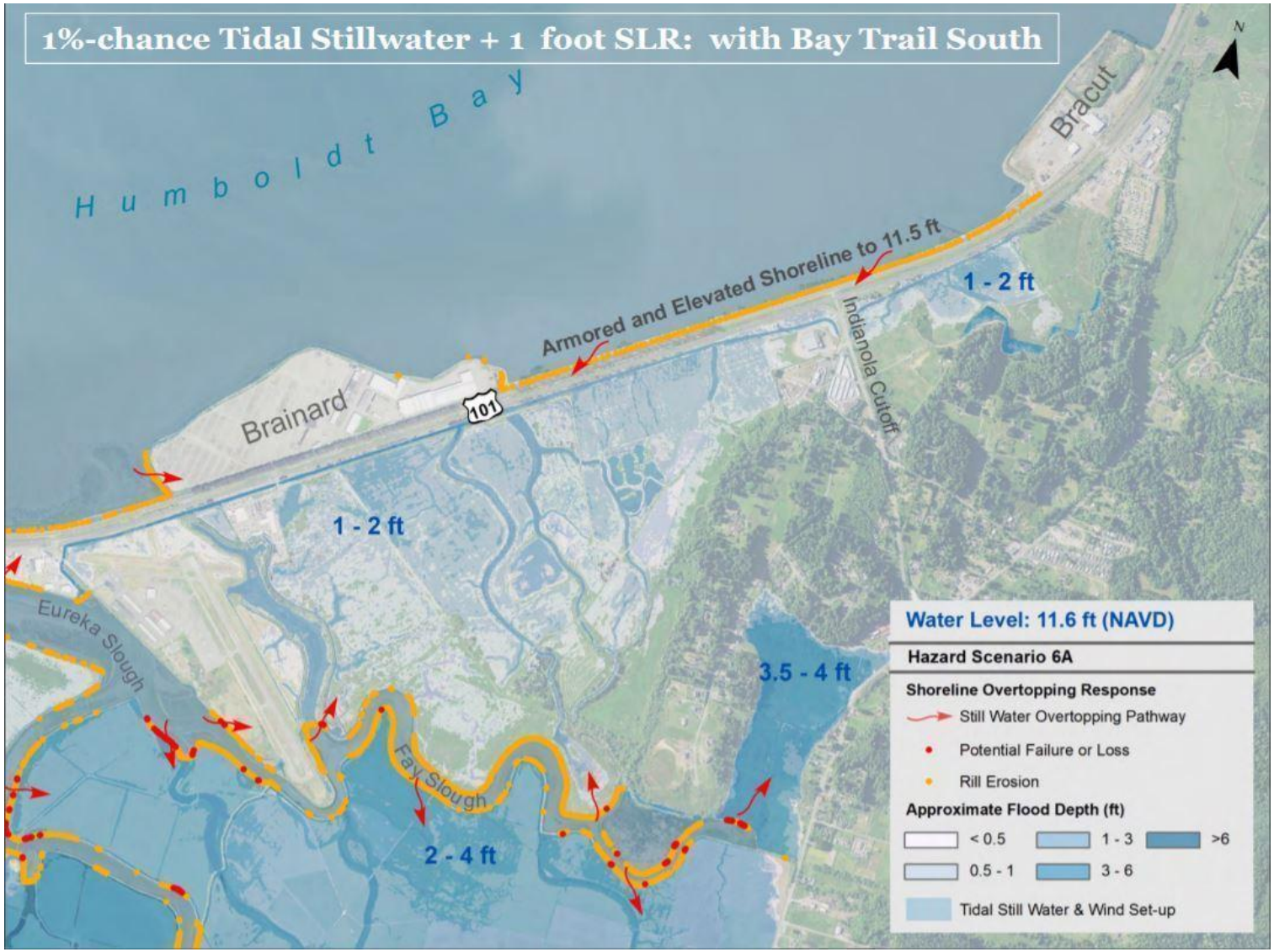

Figure 5: Flood area for 1% chance storm event combined with 1 foot of sea level rise once Humboldt Bay Trail South is completed on the 101 Highway corridor between Eureka and Arcata. Source: GHD (2021)

1.2 Characterization of Sea Level Rise in Humboldt County

SLR is a slow-acting process characterized by a gradual increase in the volume of ocean waters around the globe coupled with the thermal expansion of water. Often categorized as one of the most observable consequences of climate change, global sea levels have been rising over the past century, with an increasing rate in recent decades (Figure 6) (NOAA, 2021). The primary causes of SLR are directly related to the increase of average atmospheric temperature that has been observed across the globe in the past few decades. Water is able to absorb large amounts of heat before vaporizing and absorbs up to 90% of trapped atmospheric heat (NASA, 2021). As the temperature of water increases, the volume of the water increases. This process is known as thermal expansion and is the principal cause of the increase in the volume of oceanic waters. The other main contributor to SLR is the melting of terrestrial polar ice and glaciers. As the average temperature of the atmosphere increases, the quantity of polar ice and glaciers decreases as they melt and flow into the oceans, further increasing the volume of water in the oceans.

As this volume of water in the oceans around the globe continues to rise, the elevation of the surface waters increases with it. The problems of SLR occur when these increasing water levels begin to reach coastal developments. One of the most prevalent issues surrounding SLR is that the vast majority of pre-existing coastal developments were constructed without considering the potential for a rise in sea level. As a result, many of these coastal and "beachside" developments were built extremely close to the shoreline. With this increased level of oceanic elevation, numerous impacts can occur. As the water level increases, the risk of violent storms and nuisance flooding grows. Nuisance flooding refers to the periodic tidal inundation of coastal developments as sea levels rise, which occurs during the highest tide events, known as King Tides. Nuisance flooding also has ecological implications, and can lead to coastal erosion and reshaping coastal environments. The impacts to individuals can vary significantly depending on the type of infrastructure affected. In the case of the Humboldt Bay Trail and other trails at risk from SLR, impacts to active transportation commuters are a much greater inconvenience than impacts on vehicular commuters. Extremely disruptive and expensive to adapt to, the frequency of nuisance flooding is estimated to have increased by between 300 to 900% within U.S. coastal communities in the past 50 years (NOAA, 2021). This nuisance flooding has enormous potential for impacting coastal resources, developments, infrastructure, public utilities, and other facilities in the coming decades and beyond. When sea levels rise to the point where nuisance flooding occurs on a regular basis, it is referred to as chronic flooding, a disruptive process that can be very expensive to adapt to.

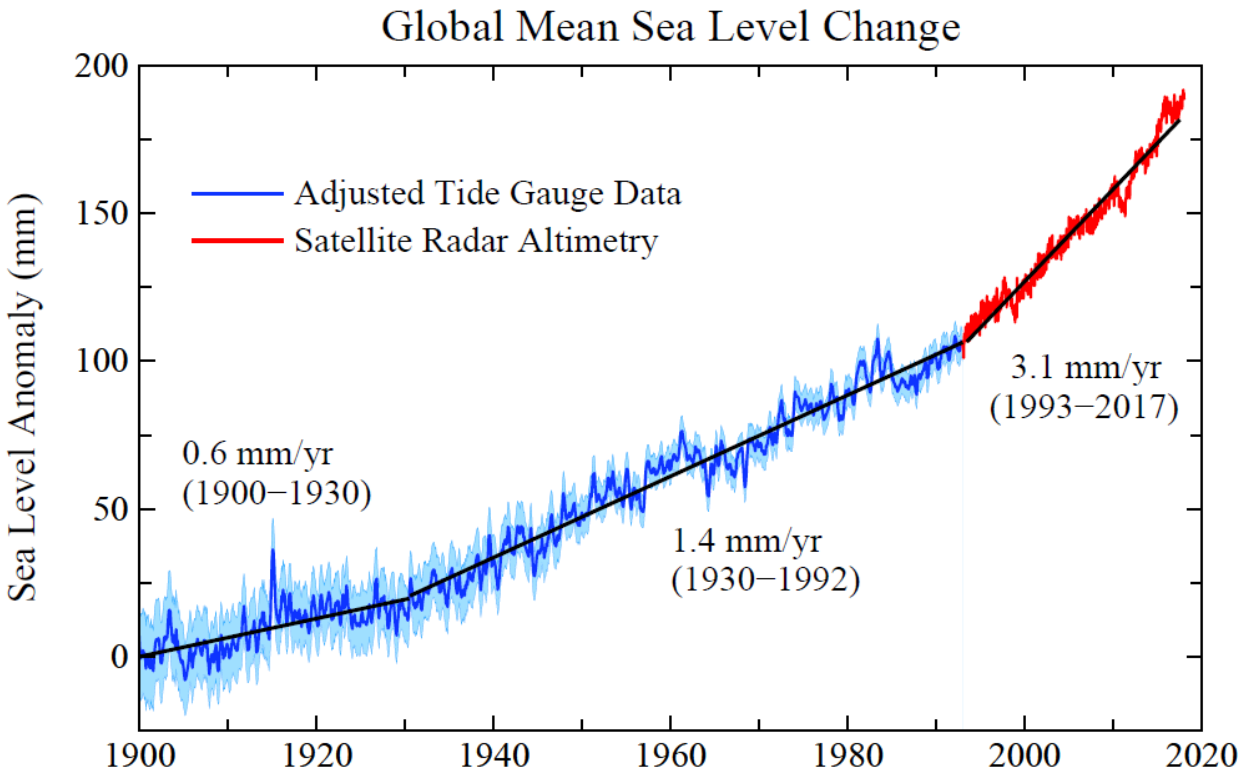

Figure 6: Global sea level rise since 1900. Source: American Geophysical Union (2018)

The impacts of SLR on coastal communities are already being seen around the world. A recent study analyzing the history of global SLR estimated that ocean elevation levels have increased by approximately 5.5 inches from the 1900s to 2000 (Kopp et al., 2016). Coastal communities have been experiencing an increased frequency of flooding and violent storms, with residents in U.S. coastal cities such as Miami and New Orleans already suffering from the impacts of SLR. Unfortunately, the rate at which the oceans are rising is accelerating, and the frequency of these storms and flooding events are accelerating with it. However, this rate of increase at which the oceans are rising is not easy to determine and is largely based on the rate at which greenhouse gases are being emitted. Due to the large amount of CO2 that have been absorbed by the oceans, SLR is expected to continue for at least 50 years, even if we are able to globally reduce emissions (Schaeffer et al., 2012). In addition to slight variations in absolute SLR rates, some communities will experience different relative sea level rise as a result of locational variations. The projections and predictions that estimate how SLR will change in the future are variable and differ from one another both in terms of intensity and timeline. These projections are based on different scenarios that examine how GHG emissions will change over time. The most severe projections are based on scenarios in which countries around the globe do very little (or nothing) to curb their GHG emissions, while the lowest SLR projections are based

on scenarios where global emissions are greatly reduced (Figure 7). Planners, engineers, and politicians often utilize the worst-case scenarios as the basis for making decisions, and it is common that higher emission scenarios are used as the basis for decision-making (Stewart et al., 2013).

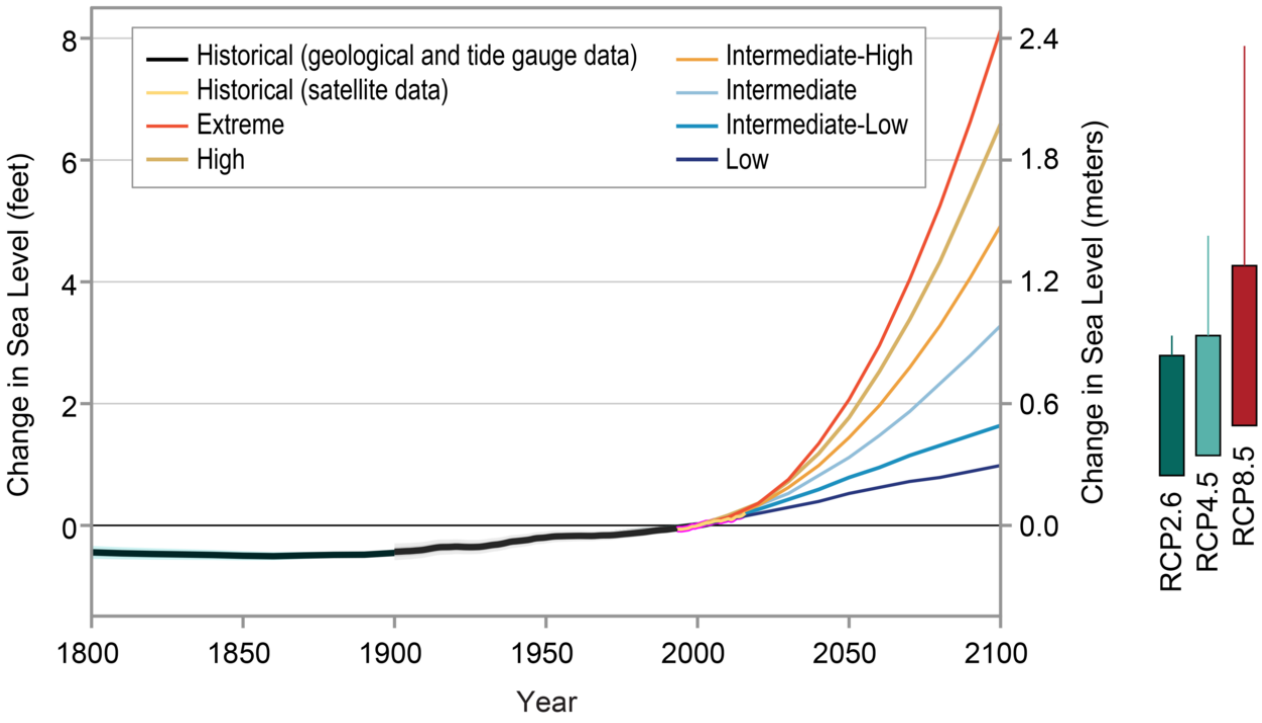

Figure 7: Various future sea level rise projections based on Emission Scenarios. Source: Natural Resources Defense Council, IPCC Report (2019)

When discussing SLR in Humboldt County, many issues need to be considered. First and foremost, the very high rate at which the oceans are rising in the Humboldt Bay Area is due to geologic factors, tectonic plates and land subsidence. A recent study published by the Humboldt Bay Vertical Reference System Working Group including members from Cascadia Geosciences, Northern Hydrology and Engineering, and Pacific Watershed Associates, estimated that the rate of sea level rise in and around Humboldt Bay is approximately 2-3 times greater than anywhere else on the West Coast (Patton et al., 2017). The projections for SLR in Humboldt Bay are based on tide elevation data collected over the past few years at the North Spit tidal gauge managed by the National Oceanic and Atmospheric Administration. Scientists from the local firm Northern Hydrology and Engineering (NHE) have utilized this data to create SLR projections for Humboldt Bay that predict how high waters in the Humboldt Bay will rise by the end of the century (Table 2). Based on more severe high emission scenarios, these projections predict 0.9 feet of SLR by 2030, 1.9 feet by 2050, 3.2 feet by 2070, and 5.4 feet by 2100.

Table 2: Rate of SLR in Humboldt Bay, with the far right column as the basis for maps. Source: Trinity Associates (2018)

SLR Planning Horizon	High Projection NHE 2014	North Spit Elevation NAVD 88	Corresponding NHE 2015 Map	North Spit Elevation NAVD 88
2030	0.9 ft.	8.6 ft.	MAMW (1.1 ft.)	8.8 ft.
2050	1.9 ft.	9.6 ft.	0.5 M (1.6 ft.)	9.3 ft.
2070	3.2 ft.	10.9 ft.	1.0 M (3.3 ft.)	11.0 ft.
2100	5.4 ft.	13.1 ft.	1.5 M (4.9 ft.)	12.6 ft.

The risk from SLR in Humboldt County is expansive. In addition to the many low-lying coastal communities around Humboldt Bay, utilities and public infrastructure will be impacted by SLR. The communities of Fairhaven, Fields Landing and King Salmon lie within extremely close proximity to the shoreline and will be some of the first communities on the West Coast to experience the impacts from SLR. A large portion of the shoreline surrounding Humboldt Bay was artificially built and developed with protective dikes to claim salt marshes for agricultural use. With just three feet of SLR, it is estimated that these dikes will be overwhelmed by tides and compromised, flooding the interior next to the current Humboldt Bay shoreline and converting approximately 10,000 acres of agricultural lands back to tidal wetlands. In addition, State Highways 101 and 255, as well as municipal water and wastewater lines, electrical distribution infrastructure, gas lines, and optical fiber communications lines, would be inundated. (Laird, 2018).

Commonly Discussed Adaptations to Sea Level Rise

No two places are exactly the same when it comes to comparing adaptation strategies to sea level rise. Different communities are unique in their population numbers and demographics, access to funds, rates of sea level rise, soil stability and composition, levels of prioritization, and so forth. Despite the “no one correct answer principle”, we examined some of the most commonly proposed or historically utilized solutions currently being explored in communities around the world, and then looked at what options are being discussed for Humboldt County coastal communities.

When analyzing literature that discusses sea level rise adaptation strategies there are common threads found throughout. Common strategies most often fall under four larger

categories: hard shoreline maintenance, soft shoreline maintenance (Indiana University 2021), land raising (Brown et al., 2019), or retreat (City of Arcata, 2017). Specific approaches within these larger categories are selected based on a multitude of factors including but not limited to feasibility, affordability, speed of implementation, community priorities, and geographic constraints. Jurisdictions predicted to be affected by sea level rise (including Humboldt County) appear to be exploring the adoption of a combination of approaches to achieve the best results.

2.1 Hard Shoreline Maintenance

Hard shoreline maintenance approaches include breakwater, bulkheads, seawalls, and revetments (Indiana University, 2021). Offshore breakwaters (Figure 8*)* are large gapped stone structures placed offshore to intercept incoming waves (Virginia Institute of Marine Science, 2017). This infrastructure is designed to take the brunt force of ocean energy and creates a "stable pocket" of calm beaches behind them (Virginia Institute of Marine Science, 2017). This strategy is not without drawbacks, primarily that this approach is satisfactory only as a short term solution, and there are limited sites that favor these structures. These shoreline protection measures are designed to primarily protect sand beaches and are not the preferred method of protection in areas with aquatic vegetation or oyster bars (Virginia Institute of Marine Science, 2017).

Figure 8: Breakwater system. Source: Virginia Institute of Marine Science (2017)

Bulkheads, often called retaining walls, are structures built along a shoreline to hold back land from being claimed by the sea (O'Neil, 1986). Bulkheads are often confused with sea walls, and most articles use the terms interchangeably, but a seawall is "retaining" the ocean instead of the land. A seawall (Figure 9*)* may act as a bulkhead but the dominant intent is to act as a hard manufactured defense from ocean energy in order to prevent erosion of the shoreline behind the wall (O'Neil, 1986). These methods of shoreline protection have often been regarded as the "go-to" short-term solution, but are not without drawbacks. The National Park Service acknowledges that while structures behind walls are protected, these methods of protection accelerate erosion on adjacent beaches and at the base of the wall, are not a permanent (long-term) solution, and should be removed when possible to restore natural coastline processes (NPS, 2019).

Figure 9: Large seawall located at Christiansted National Historic Site, Virgin Islands. Source: National Park Service (2019)

A further approach to hard shoreline maintenance is revetments. Revetments prevent scour from currents and waves and deflect wave energy up the slope face. A revetment (Figure 10*)* unlike a seawall is not self-supporting and instead requires the support of the soil beneath it (U.S. Army Corps of Engineers, 1981). Revetments are often made up of large boulders with limited infill, and if found on a coastline may have a separate sea wall behind them. The

Humboldt Bay Trail and the railroad prism on which it exists act in the same protective manner as a revetment, and are a crucial short-term protective measure along the Humboldt Bay.

Figure 10: Revetment near the ferry dock at Jean Lafitte National Historical Park and Preserve, Louisiana. Source: National Park Service (2019)

2.2 Soft Shoreline Maintenance

When addressing shoreline maintenance there is a sliding scale of "unnatural" hard shoreline approaches and what are regarded as "more natural" soft shoreline approaches (Figure 11*)*. Important soft shoreline approaches include living shorelines, dune creation, and planting submerged reefs or vegetation (Indiana University, 2021). NOAA predicts that by the year 2100, 33 percent of United States shorelines will be hardened, resulting in decreased biodiversity and creating seaward erosion (NOAA, n.d.). This prediction may be why living shorelines (also called Natural Shorelines) are emphasised in the State of California. Living shorelines function as natural ecologically beneficial coastal defense systems (Coastal Commission, 2018, p. 123). They take many forms but are broadly described as artificially created natural erosion and coastline flooding barriers that also provide essential ecosystem services to coastal shorelines (NOAA, n.d.).

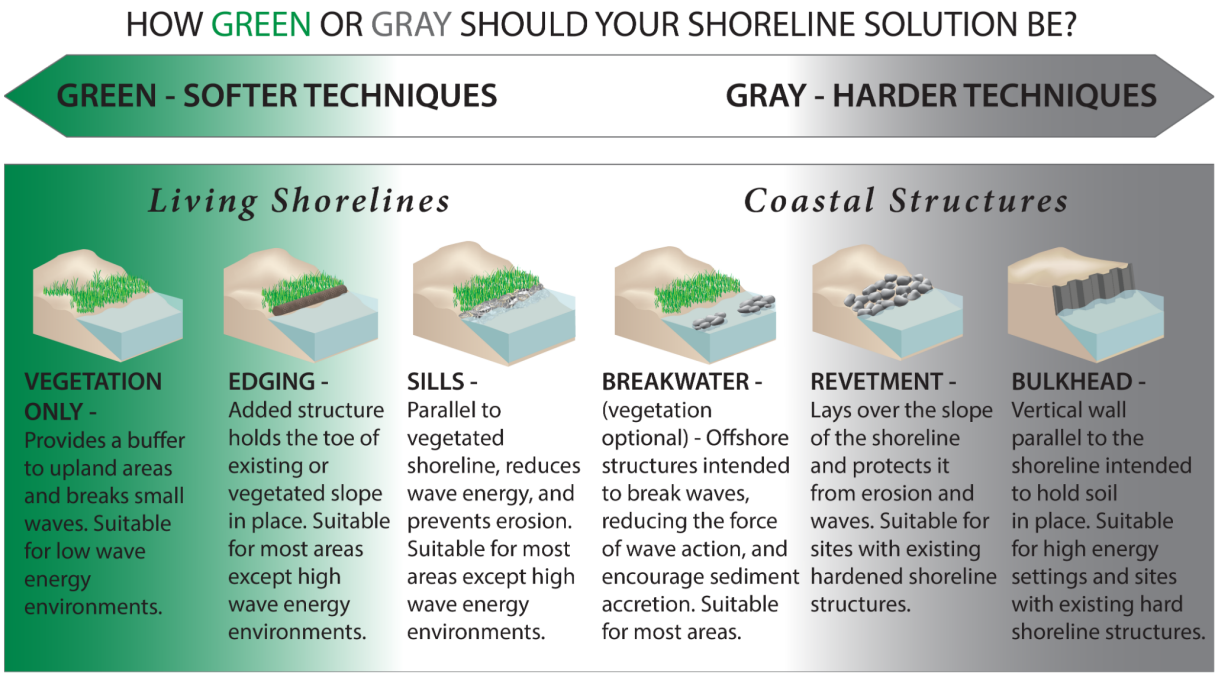

Figure 11: Soft versus hard shoreline protection techniques. Source: NOAA (n.d.).

Another soft shoreline protection approach is dune creation. This is the process of establishing dunes on the inland areas of beaches, often "armored" through the introduction of grasses or fences (Figure 12*)*. Dune creation has benefits of establishing habitat for specialized sensitive species, while at the same time armoring the shoreline against storms, erosion, and supplying beaches with sand (Pennsylvania State University, n.d.). This practice is currently being undertaken in the Cape Cod area of Massachusetts to adapt to erosion caused by strong winter storms (Pennsylvania State University, n.d.). Considering the impact of introducing invasive dune grass species is a crucial consideration in using this adaptation method.

Figure 12. Established dunes fortified by dune grass and fence. Source: Patten (2016)

An additional soft shoreline approach is one that in some cases will not even be seen from the shore. This approach is the introduction of reefs, seagrasses, or other types of aquatic vegetation. These “planted” barriers act as buffers that protect shorelines from waves, flooding, and storm surges (NOAA, 2021). A current United States West Coast approach involves the planting of kelp forests (Figure 13). Not only do kelp forests serve as a wave energy and erosion buffer along the coastline, but kelp has an extraordinary ability to sequester carbon dioxide (20 times more per acre than forests) and provide habitat for endangered species (Browning et al., 2020).

Figure 13: Bull Kelp. Source: Browning 2020

2.3 Land Raising

Raising land is a practice that has been undertaken worldwide, and is most often seen in infrastructure projects. The idea is simple in principle: raise land to meet the predicted height needed to avoid inundation for a set amount of sea level rise or storm surge. This tactic has already been employed on a large scale in the Maldives. The Maldives, in an effort to continue population expansion and prevent flooding from sea level rise, manufactured a whole new raised island (Figure 14*)* to better stave off sea level rise hazards (Wadey et al., 2019). This prospect is often thought of as a short-term solution. Due to the constant need for elevation adjustment in order to keep up with the increasing rate of sea level rise, it becomes a bottomless pit of monetary cost.

Figure 14: Hulhumale in the Maldives. Source: Miller (2020)

2.4 Causeway

A causeway refers to a design feature of an elevated track or roadway that has been constructed at the top of a raised embankment. Such structures are often built over areas of low, wet environments or bodies of water. There are two primary design approaches for constructing causeways. The first is to form a raised embankment of land of higher elevation than the area surrounding it. The transportation path is then constructed atop the raised embankment. The second approach is to develop a path on top of an elevated bridge structure (Figure 15). This design, sometimes referred to as a viaduct, allows for water to flow freely underneath the elevated path. Although these structures can be effective SLR adaptation methods, they can be very expensive to develop and construct.

Figure 15: Raised Causeway in Louisiana. Source: Kanjilal (2017)

2.5 Retreat

The final major category of sea level rise adaptation being globally considered is retreat. This principle is simple to understand but difficult to plan for and implement. Retreat involves the relocation of people, property, and infrastructure out of the zone of predicted sea level rise inundation areas (Figure 16). Due to constraints of communities (space, funds, legality, local pushback), the planned relocation of people, property, and infrastructure is more feasible over a long period of time. This means that this strategy is typically undertaken in conjunction with a variety of other strategies including but not limited to the previously mentioned armoring and land raising techniques.

Figure 16: Eroding coastal development. Source: Hossfield (2020)

2.6 Gaps in Knowledge

The science of sea level rise is relatively new, and communities are facing an uphill battle dealing with uncertainties. Three main uncertainties and gaps in knowledge are cost variation in adaptation measures, changing predictions in the rate of sea level rise, and limited funding sources to assist with responses to SLR. When a community wants to undertake a large project like sea level rise adaptation infrastructure, assessing feasibility is a critical beginning step. Feasibility relates to a lot of factors, one of which is cost or affordability. Cost assessment is extremely difficult with infrastructure projects like sea level rise adaptation measures. The Intergovernmental Panel on Climate Change echoes this point saying, “Data on the costs of hard defences is only available for few countries and unit costs estimated from this data vary substantially depending on building/fill material used, labour cost, urban versus rural settings, hydraulic loads, etc” (IPCC, 2019, p. 89). This means that for accurate project cost predictions communities will have to undertake comprehensive project cost assessment and site studies to determine project feasibility. Unfortunately, such assessments are costly and bring with them delays in project selection, implementation, and completion.

Sea level rise predictions were scarce just decades ago, but since their inception predictions have varied wildly. Each geographical area is unique and so looking at global sea level rise predictions is not a good basis for communities to plan from. The Intergovernmental Panel on Climate Change highlights that the rate of sea level rise changes in different eras, and has been increasing in the modern era. For example, the Global Mean Sea Level rise recorded from tide gauges and altimetry observations were 1.4 mm/yr in 1901-1990, 2.1 mm/yr in 1970-2015, 3.2 mm/yr 1993-2015, and finally 3.6 mm/yr in 2005-2015 (IPCC, 2019). Due to the consistently increasing SLR prediction rates, government entities need to update the predictions that they base their adaptation planning on and err on the side of caution. Changes in SLR predictions result in discrepancies between entities. The CalTrans Eureka-Arcata Corridor: Sea Level Rise Vulnerabilities and Adaptation Solutions document discusses for example, how three previous sea level rise assessments included all different metrics. These metrics taken as recently as 2018 were not sufficient for the California Coastal Commission which set three guidance thresholds, "a low risk SLR scenario of 4.1 feet by 2100, a medium-high of 7.6 feet, and an extreme risk of 10.9 feet" (CalTrans, 2019, p. 5). The frequency with which guidance on sea level rise planning changes, makes it extremely difficult for communities to assess the necessary specifications for shoreline protection measures.

The final major gap in knowledge communities face when attempting to adapt to sea level rise is finding funding. As mentioned in the paragraphs above, when communities navigate through the issues of clarifying the rate of sea level rise and deciding upon viable solutions that are going to be considered, the practicality, feasibility, and longevity aspects of adaptation are largely dependent on the affordability component. Large agencies often have dedicated funding sources that are allocated for adapting to sea level rise (Table 3). Once sources of funding are found, securing adequate funds to implement a project can be very difficult. Due to the scope of sea level rise, and the critical infrastructure it threatens, large amounts of funds are diverted to higher priority projects (like major transportation corridors, ports, urban hubs). Communities and projects further down the list of priorities will have to be more creative, make a bigger case, and more than likely expect longer waiting times to receive funds. This may mean beginning the application and search process early.

Table 3: Short list of potential funding providers for sea level rise adaptation

Potential Funding Agencies
FEMA
U.S. Department of Housing and Urban Development (HUD)
NOAA Coastal Resilience Grant Program
Ocean Protection Council
State Coastal Conservancy
California Coastal Commission
USGS Provides Scientific Research and SLR Modeling
U.S. EPA

Stakeholder Analysis and Interviews

There are dozens of stakeholders for transportation in the Humboldt Bay Area (Figure 17) and interviewing them all would have been infeasible for the scope of this project. Instead of trying to capture the opinions of every stakeholder in this project, we chose to interview seven public officials and non-profit leaders to explore a range of perspectives on the future of the regional trail system and demonstrate the variety of agency involvement in trails. Each interviewee presented a unique perspective and is involved in a different aspect of trail planning while also being responsible for representing the interests of the public. See Table 4 for a summary of concerns and recommendations going forward that we identified from our interviews. A full list of the stakeholders that we identified in this project can be found in Appendix D.

3.1 Methods

A large component of our project was interviewing a number of people who are working closely with the Humboldt Bay Trail project. Sea level rise planning is a multidisciplinary process that crosses jurisdictional boundaries and impacts everyone in a coastal community. Because of this, we tried to glean a wide array of perspectives on what is being planned. We spoke with a city council member, Humboldt County officials, CalTrans employees, the director of a local non-profit, and a local sea level rise planner. Our goal in conducting these interviews was to learn more about the project in general from the experts that are working on it and understand the vision that each stakeholder has for the future of trails in Humboldt County.

We conducted interviews with the approval of the HSU Institutional Review Board and collected contact information through internet sources and communication with our project

clients. We began by having a discussion with our project clients about who is involved in this process already and getting a list of local experts that we could interview. Next we emailed potential interviewees with information on our project and asked to interview them. Once potential interviewees responded to our introductory email, we followed up by providing an informed consent form and a variety of dates and times that we had available. Once we received the consent form back from the interviewees, we finalized a date and time for our interview to be held via Zoom. Each interviewee was asked a set of standard questions relating to SLR adaptation planning, HBARTS in general, and concerns going forward, as well as a couple of personalized questions for their specific perspective or job expertise. Interviews ranged 20 minutes to an hour. A list of all of our interview questions can be found in Appendix C.

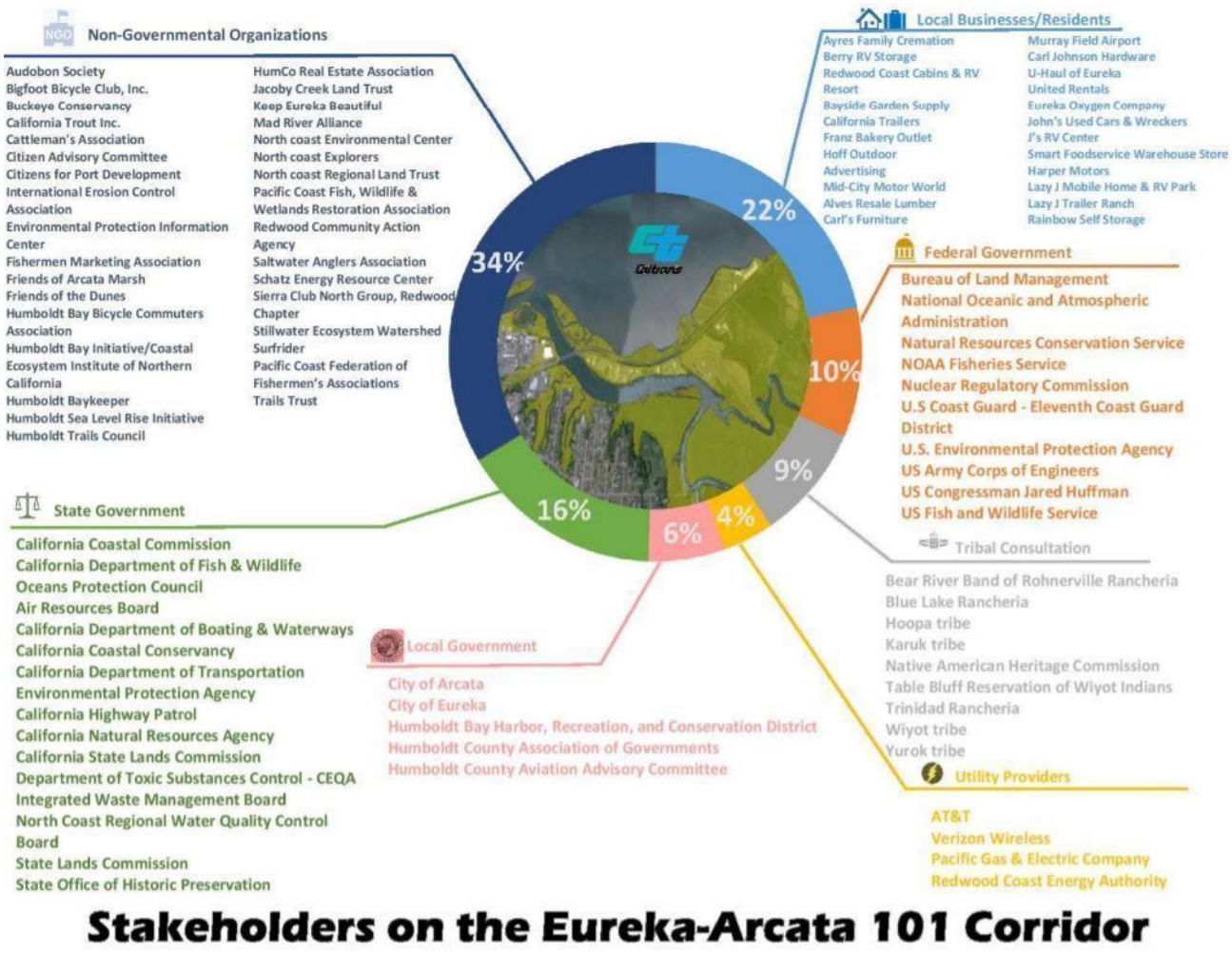

Figure 17: A breakdown of stakeholders on the Eureka-Arcata 101 highway corridor. This includes stakeholders outside of the scope of our project. See Appendix D for a table of the stakeholders associated with our project. Source: Alvarez et al (2020).

3.2 Locally Explored Adaptations and how they Relate to HBARTS

In our various discussions with community planners and elected officials, we attempted to gain a broader understanding of discussed or planned community adaptation strategies. In this section, we focus on activities being planned or discussed as a future adaptation measure, as well as ones currently being implemented today. As there are many different organizations and stakeholders—often with differing goals and objectives—one of the most important aspects is how effective the collaboration and communication between different stakeholders involved is. Although there has been effective communication between stakeholders collaboratively working on projects within the Humboldt Bay region in the past, many of the jurisdictional complexities associated with this project have resulted in unsatisfactory communication and collaborative efforts. One of the central topics discussed in our interviews was the need for effective communication and collaboration, and all of the stakeholders interviewed agreed that enhanced communication would be beneficial and valuable.

The soon-to-be-completed trail gem of Humboldt County, the Humboldt Bay Trail, is the shining example of a securely funded and community supported alternative transportation infrastructure. The historic railroad prism on which it will exist functions as a short-term shoreline armoring system. As the sea level rises, the Bay Trail will have to be periodically raised and reinforced in order to remain consistently functional in its current location. Hank Seemann of Humboldt County Environmental Services said to us in an interview that the principle of increasing land height to account for a certain level of sea level rise will be implemented in the remaining section of the Humboldt Bay Trail. He also said it is likely that this process may need to happen again in the future to keep up with the increasing sea level over time. An important point Seemann mentioned was that the completed iteration of the Humboldt Trail as it is currently envisioned is expected to last between 30-50 years. This means that this infrastructure as a trail and shoreline armoring structure is considered a short-term solution and will help buy time for future adaptation strategies. Even though this iteration of the trail may not make it into the next century, it will be crucial in establishing active transportation in this region at present.

Aldaron Laird of Trinity Associates stressed the importance of a long planning horizon for SLR issues. Beginning with the projections used, we've seen sea level rise projections for the year 2100 move from about 3 ft. in 2010 to 8 ft. in 2018. With the lack of certainty around the actual rate of SLR that we will experience, planners should be using the more extreme projections. Once something is built, it's very difficult and expensive to move it so planning should be done with extreme scenarios in mind. Laird mentioned the City of Eureka had previously come to an agreement with the North Coast Railroad Authority to allow portions of trail construction along the railroad grade. However, Laird also brought up the fact that keeping the Bay Trail near where it is for the next iteration may not remain feasible. Instead, he suggested a location parallel to Hwy 255 to mimic the path that the Wiyot people would take around the Bay, or moving the trail inland along Old Arcata Road. By the year 2100 we can expect that

much of Eureka and Arcata will be tidally underwater so it is important to begin planning a new location that will be safe for the next century.

Due to the short term nature of land raising adaptation strategies, Humboldt County is implementing another protection technique, natural (or living) shorelines (Humboldt County, 2021). This project's implementation design and feasibility study is expected to be completed in December of 2021 and will serve as the county's foundation for longer term approaches to sea level rise adaptation if implemented. There are high hopes for natural approaches to shoreline protection, but natural shorelines are not always a solution. Oona Smith, Senior Planner, Humboldt County Association of Governments, expressed to us that natural barriers are effective at slowing down wave energy but they are very expensive and require land to grow and expand. Aldaron Laird added that while living shorelines are effective in the short term, they lose effectiveness as sea levels rise especially if there is no excess land available for shoreline conversion.

Another local focus on concerns about sea level rise adaptation of the Humboldt Bay Area community is what is going to happen with the Hwy 101 corridor between Eureka and Arcata. In an interview with Clancy De Smet (CalTrans Climate Change Adaptation Branch Chief) and Lorna McFarlane (CalTrans District 1 Senior Coastal Liaison), we discussed the possible adaptation strategy progression of the Hwy 101 corridor. An important precursor to this section is that the Comprehensive Adaptation Plan is not set to be completed until 2025. That being said, De Smet and McFarlane said that it is likely multiple approaches will be undertaken to combat the threat of sea level rise. Measures discussed included: raising the railway fill prism (part of the Bay Trail project), protection via levee, reconstruction (via causeway or viaduct), and living shorelines. De Smet and McFarlane emphasized that individual sections of the corridor may be treated differently depending on the individual scale of the threat. This means that when these adaptation measures take place it is unlikely that a complete raised causeway will be initially undertaken for the whole of the corridor. De Smet and McFarlane said that this does not mean that in the long term the whole roadway will not eventually become a causeway, it is a matter of feasibility and necessity. Caltrans seeks to set the example on climate action and multimodal transportation. Our interview respondents indicated that Caltrans would likely be open to including the Humboldt Bay Trail on the causeway and stressed the importance of public engagement, especially early on in this process.

A necessary adaptation to sea level rise expected to be undertaken by the two largest cities in Humboldt County (Eureka and Arcata) is measured retreat. In an interview with Natalie Arroyo, a Eureka City Council member, we learned that coastal retreat will be a necessary tool used by the city, where possible. Councilwoman Arroyo suggested that the Jacobs Avenue area will have to be relocated over time, and in the meantime, critical infrastructure will need to be raised until more comprehensive long-term solutions can be implemented. As this process relates to trails, Councilwoman Arroyo expressed her opinion that it would be infeasible to consider land raising as a long term solution due to cost and difficulty associated with soil compaction on the Eureka Waterfront Trail. This means that those trails located adjacent to the Bay will need to

be relocated, much like the lower elevation city infrastructure. Retreat is recognized as a priority long-term community adaptation for the City of Arcata as well (City of Arcata, 2017). These cities are doing their best to maximize the current utility of the land that is inevitably going to be lost to sea level rise. In regards to sea level rise action, Councilwoman Arroyo emphasized that it's important to implement what is feasible while still keeping in mind the threats of the future. Potential future projects for the City of Eureka include trail access towards Fields Landing and King Salmon, a trail to the College of the Redwoods, and a Bay to Zoo trail.

Finding support for active transportation projects is difficult with the lack of data and precedent when compared to vehicle travel. Oona Smith noted that sometimes the support for trails does not come until the trail is built. When it comes to alternative transportation infrastructure, it is important to plan, take action, and promote progress all at the same time. Keeping the pressure on the topic of active transportation will be key going forward in order to address the climate crisis. She added that focusing on local climate goals is not nearly as important as reaching global targets on climate change. In most cases, elected officials and staff want to take action on climate change and transportation safety and simply lack the funding.

Finally, an important approach being locally undertaken is outreach and education. If people are unaware of or can't understand an issue, gaining public support for a physical adaptation plan or measures will be much more difficult. In an interview with Emily Sinkhorn, Natural Resources Services Director with the Redwood Community Action Agency, we found out about RCAA's program to incorporate discussions about climate change and sea level rise into K-12 schools. This process aids in the creation of an informed public that will be more willing and able to tackle the large climate change induced issues threatening the county. With the lack of funding available for active transportation projects, it's more important than ever that the public is aware of and advocates for the benefits that these projects provide.

Table 4: Summary of concerns and recommendations identified from our interviews

Concerns	Recommendations
Establishing effective communication and collaborative planning processes between stakeholders	Creating a specialized committee/working group designed to encourage and facilitate collaboration on these projects
Getting more people to participate in active transportation	Actively plan and do at the same time. Sometimes people don't participate until the infrastructure exists.
Public engagement early on so that everyone's voices and ideas are able to be heard	Broad planning approach to see what can reduce driving. Collaborate in order to be able to include the trail in a potential future raised causeway
Expand the existing trail network south of Eureka to provide access to College of the Redwoods and better emergency options for Kings Salmon and Fields Landing.	Continue the collaborative work that has gone into the Humboldt Bay Trail to keep up the momentum of active transportation
Ensuring trail is durable enough for the investment in infrastructure to pay off	Build up the existing railway prism to buy time for further adaptation measures. Natural barriers are best in the long run but are space and money intensive.
Erosion of railway prism and loss of effectiveness of living shorelines over time. The 101 corridor is already vulnerable if some of the dikes were to fail.	Use the most extreme SLR projections for planning because our predictions keep moving in that direction. It's important to begin planning infrastructure projects early due to the long planning horizon.
Reducing Vehicle Miles Traveled (VMT) in order to meet California climate goals	Ensure projects have a way to collect data besides VMT so that future projects have a foundation of support.
Getting people to think regionally in regards to transportation and land use	By 2120 the tide will reach Old Arcata Rd., so it could be worth separating the trail from the highway. Move the trail to a better long-term location.
Securing funding for more active transportation projects and expanding the existing trail systems	Invest lightly in trails that will soon be impacted by SLR. Implement what is feasible while keeping in mind future threats.
Educating youth about active transportation and sustainable practices	Create educational materials on SLR, climate change, active transportation and waste reduction for K-12 students

Conclusion and Recommendations

This research and outreach identified several key challenges and opportunities for adapting the Humboldt Regional Trail System to the impacts of SLR. Our key recommendations —which are based on the long-term goals of climate mitigation, climate adaptation and improving alternative transportation options and infrastructure—focus on enhanced stakeholder communication and collaboration, considerations for design and structural components, and emphasizing the importance of carrying momentum and influencing behavior for achieving long-term ambitious climate and transportation goals.

4.1 Communication and Collaboration

Jurisdictional oversight of HBARTS is fragmented and complicated. In order to formulate a coherent plan for its future and adaptation options for its protection, stakeholders will need to collaborate. All interviewees we talked to support implementing some form of active transportation option. Additionally, the majority of the interviewees that we spoke with agreed that communications and collaboration between these different groups is necessary to achieve the desired goals of SLR adaptation and options for alternative transportation. Furthermore, some interviewees went as far as to acknowledge that the collaboration and communication that has occurred thus far has been inconsistent and insufficient, and has helped to contribute to the long delays and costs associated with starting projects.

We recommend that an explicit committee for communicating about and collaborating on the intersection of alternative transportation options and SLR adaptation approaches be established, consisting of major stakeholders and anyone who wishes to be involved. Such a group would meet on a semi-regular basis and discuss the current status of planning processes. If a particular project or component of a project is being deliberated then lead agencies or project proponents can lead the discussion on that particular project.

This group could resemble a committee and would collaboratively focus on this topic. This would allow for more informed and controlled project planning, broaden funding opportunities, and overall, promote collaboration on complex topics and decisions.

4.2 Design and Structural Considerations

After considering the research and data collected throughout this process, we have several recommendations focused on ensuring that the trails are established, maintained, and protected from sea-level rise in the short and long term.

4.2.1 Trail Construction on Railroad Grade

An effective measure for trail construction and protection in the short term is to build the trails along the railroad prism. Constructing the trails on this grade will increase their elevation and provide them with a buffer slope to protect them from the projected short term effects of sea level rise. This strategy can also bring in much-needed maintenance dollars to restore these strips of land that would otherwise not have been maintained. A project like this would require more collaboration between the North Coast Railroad Authority and the various jurisdictions that own

the land under each portion of the trail. This precedent has been established and the concept is considered feasible in the short term. There are a few different adaptation measures that are being considered in the event that the trail is constructed upon the prism. One of these options is to incrementally and gradually raise the railroad prism as the elevation of the bay rises. Although this could be an effective adaptation measure, it would likely require the reconstruction of the trail surface as the land below needs to be elevated. Although this strategy can provide short term planning solutions, it would be too costly and involved to consider as a long-term solution. The railroad grade between Arcata and Eureka is projected to be inundated by sea level rise within 30 to 50 years according to Hank Seemann, so other strategies will need to be employed to ensure trail protection and access into the future.

4.2.2 Raised Causeway with Trail Included

As previously mentioned, Caltrans is exploring the possibility of constructing a raised causeway for the Highway 101 corridor between Arcata and Eureka to protect the road from the effects of sea level rise. It is this report's recommendation that if the decision to develop a causeway occurs, the considerations should include the Humboldt Bay Trail being constructed along the causeway, similar in principle to the Golden Gate Bridge in San Francisco. This strategy would provide protection from sea level rise to both pieces of infrastructure by moving them up and away from the rising waters. This adaptation alternative also would ensure the road is protected while still providing an active transportation alternative in the corridor for those who choose to use it. The causeway project is something that has been discussed extensively over the past year and will continue to require extensive collaboration and planning in order to be implemented. Inclusion of the Humboldt Bay Trail as part of this major infrastructure project would highlight the region's desire to encourage multi-modal transportation, reduce vehicle miles traveled, and preserve the scenic views of the Humboldt Bay Trail.

4.2.3 Trail Relocation Inland

Our final design and structural recommendation reflects the most long-term planning horizon. In order to effectively protect the HBARTS from the effects of sea level rise, any trails not on a causeway will need to be relocated further inland (same as other forms of coastal development). The main objective for choosing a location for these trails should be the question, "Where do we want these trails to be 100 years from now?" Following this general guideline, there are a few different important considerations to keep in mind. The first and perhaps most important consideration is access. We need to ensure that the location of the trails is easy and convenient for the general public to access without the use of motor vehicles. The most optimum locations for trail access points would be close to neighborhoods, housing developments, or already existing popular active transportation routes. The next consideration to keep in mind is the walkability or feasibility of using active transportation methods. This means that the trails should not run through any steep hills. If hills need to be considered in the most optimum path, the path will have to wind along them on a path that is cut into the hill slope. This strategy would be expensive and time-consuming, but it is the best available method to ensure that the HBARTS is protected from sea level rise for the long-term future.

4.3 Induced Demand, Influencing Culture, and Carrying Momentum

In reflecting on the findings from our interviews, we noticed a common thread from all Humboldt County community leaders. There is a recognition that multi-modal (alternative) forms of transportation can and should be increased within the county. In the previous section, we discussed our recommendations for the future, but ideas are not implemented without a clear way forward.

The principle of induced demand, in the context of this project, is the idea that investing in more multi-modal (alternative) transportation infrastructure will result in an increase in that alternative transportation. This principle is often championed by organizations, like the Coalition for Responsible Transportation Priorities, who advocate for an increase in infrastructure investment. However, sometimes through lack of local support or demand they find it more difficult to influence or drive project implementation. Public support can in fact result in major success stories like the Bay Trail, which was funded and constructed largely due to broad local support that spanned across multiple decades. Recent evidence supports advocating for this type of infrastructure development. A recent study titled "Provisional COVID-19 infrastructure induces large, rapid increases in cycling" (Kraus et al., 2021), examined the cycling increase on average in 106 European cities as a result of post-COVID-19 bike lane pop-ups. Findings concluded that there was on average an 11-48 percent increase in cycling and potentially billions of dollars in health care costs saved as a result (Kraus et al. 2021). There are indicators that this same phenomenon can occur in America as well. Two things were sold out during the pandemic in the United States: toilet paper and bicycles. Every major news source at some point in the last year and a half has displayed a headline similar to "The great bicycle boom of 2020" (Bernhard, 2020). In April, 2020, bike sales nationwide grew by 75% and 63% in June (Tracy, 2020).

What this means is that there has never been a better time to introduce new projects protecting, creating, or updating cycling infrastructure in the area. The heavy lifting task of influencing culture towards alternative forms of transportation has already been completed by COVID-19. There may not be another chance for a long time to begin alternative transportation infrastructure development talks, where the public baseline for support is this favorable. The world economic stage was halted by Coronavirus lockdowns, and the recovery currently taking place can be stimulated through investment in alternative transportation infrastructure. Cyclists are estimated to spend 3 times more money than car users at local businesses (Schwedhelm et al., 2020). Sea level rise is threatening HBARTS in the near future. Demand for purchasing bicycles has never been higher. The current global community interest for cycling infrastructure is so strong that "pop-up" or emergency bicycle lanes are opening globally. Coupled with communities desperately needing a strong revenue stream means that the time for a collaborative effort to reorganize and update alternative transportation infrastructure may never have the chance to be as impactful as it currently is.

Table 5. Summary of recommendations

Recommendation	Summary of Recommendation
4.1 Communication and Collaboration	The report group recommends the creation of a committee whose expressed purpose is to address SLR and the future of HBARTS. This committee can be composed of key stakeholders in the region, and needs to be open to the public for their comments and critiques.
4.2 Design and Structural Considerations	We recommend three strategies with different planning horizons for protecting the trail system from sea level rise. The first strategy is to construct trails along the railroad grade. This short term adaptation will elevate the trails with a gentle slope to mitigate negative effects. The second strategy is to construct a raised causeway for the Highway 101 corridor with the trail included. This will ensure that both the road and trail are elevated away from potential sea level rise danger. The third strategy with the longest planning horizon is to relocate the trails further inland. This strategy will ensure that sea level rise will not affect the trail system but choosing optimal paths will present further difficulties.
4.3 Induced Demand, Influencing Culture, and Carrying Momentum	To meet the state's ambitious climate goals and encourage the usage of alternative transportation measures, communities need to take a hard look at the principle of induced demand. This principle has the power to influence culture and change the way people view the concept of transportation. There has never been a more favorable time to push for sustainable, multimodal forms of transportation. We recommend using this wave of pandemic fueled momentum to further introduce and explore alternative transportation infrastructure projects.

4.4 Conclusion

Following this transitional wave, decision-makers with influence over HBARTS will have an opportunity to immediately begin public engagement sessions focusing on the future of trails in the Humboldt Bay area. If the desire to invest in a more robust alternative transportation system is to be met, there can be no gaps in progress. Momentum in the public sphere often follows the slightly adapted principle of Isaac Newton's First Law of Motion: "an object in motion tends to remain in motion." There is evidence that when growth (in this case of trail infrastructure) stagnates it is extremely difficult to restart, and may result in the inability to successfully restart (Christensen et al., 2013 p. 5). Habits are only formed when there is steady repetition, and this means that if there is 20 year delay between the current iteration of the Humboldt Bay Trail and the next, users will be forced back into vehicles ultimately undoing all the progress that has been and is currently being made. Fragmented jurisdictions, lack of certainty surrounding SLR projections, and long-term planning horizons all point towards the importance of immediate collaborative planning. Each community faces unique challenges and our recommendations are based on the setting of Humboldt Bay. However, there is much from our report that can be applied to active transportation planning, sea level rise adaptation, and collaborative planning processes in other coastal communities around the world. A summary of our recommendations can be found in Table 5.

References

Alvarez, J., Orozco, D., Ponce, P., Premo, T., & Tatian-Burger, R. (n.d.). *Stakeholder Analysis Related to Sea Level Rise Adaptation and Planning for the Eureka-Arcata 101 Corridor*. 70. https://digitalcommons.humboldt.edu/cgi/viewcontent.cgi?article=1007&context=hsuslri_student

Bernhard, A. (2020). The great bicycle boom of 2020. Retrieved April 14, 2021, from https://www.bbc.com/future/bespoke/made-on-earth/the-great-bicycle-boom-of-2020.html

Business Performance Improvement Resource. (2021). *Collaborative Tools and Methodologies*. BPIR. https://www.bpir.com/collaborative-tools-and-methodologies-/menu-id-71/expert-opinion.html

Brown, S., Wadey, M., Nicholls, R., Shareef, A., Khaleel, Z., Hinkel, J., . . . McCabe, M. (2019, October 07). Land raising as a solution TO SEA‐LEVEL Rise: An analysis of coastal flooding on an artificial island in the Maldives. Retrieved April 12, 2021, from https://onlinelibrary.wiley.com/doi/full/10.1111/jfr3.12567

Browning, J., & Lyons, G. (2020, May 27). 5 reasons to Protect kelp, the West COAST'S POWERHOUSE marine algae. Retrieved April 12, 2021, from https://www.pewtrusts.org/en/research-and-analysis/articles/2020/05/27/5-reasons-to-protect-kelp-the-west-coasts-powerhouse-marine-algae#:~:text=3.-,Protect%20the%20shoreline,filter%20pollutants%20from%20the%20water

California Coastal Commission. (2018, November 7). CALIFORNIA COASTAL COMMISSION SEA LEVEL RISE POLICY GUIDANCE. Retrieved April 12, 2021, from https://documents.coastal.ca.gov/assets/slr/guidance/2018/0_Full_2018AdoptedSLRGuidanceUpdate.pdf

CalTrans, & ICF. (2019, May). Caltrans Eureka-Arcata Corridor: Sea Level Rise Vulnerabilities and Adaptation Solutions. Retrieved April 12, 2021, from https://digitalcommons.humboldt.edu/cgi/viewcontent.cgi?article=1007&context=hsuslri_state

City of Arcata. (2017). Sea Level Rise Draft Policies. Retrieved April 12, 2021, from https://www.cityofarcata.org/DocumentCenter/View/6429/Arcata-Sea-Level-Rise-Policies-DRAFT-June-2017?bidId=

Christensen, C., & Raynor, M. (2013, November 19). The Innovator's Solution: Creating and Sustaining Successful Growth. Retrieved April 28, 2021, from https://books.google.com/books?id=I5nBAgAAQBAJ&dq=is+it+harder+to+reignite+public+interest+in+a+cause+more+difficult+than+maintaining+it&lr=&source=gbs_navlinks_s

Cornell, S., Fitzgerald, D., Frey, N., Georgiou, I., & Hanegan, K. (n.d.). Coastal Dune protection and restoration. Retrieved April 12, 2021, from https://www.e-education.psu.edu/earth107/node/1072

County of Humboldt. (2016, June). Expanding Regional and Local Trails in Humboldt County. http://hcaog.net/sites/default/files/humboldt_trails_brochure_june_2016_fullsize_0.pdf

County of Humboldt. (11/17). *Humboldt Bay Trail Projects Overview Map*. https://humboldtgov.org/DocumentCenter/View/62358/Humboldt-Bay-Trail-Projects-Overview-Map-November-2017?bidId=

GHD. (2020, January). *Proposed Trail Alignment and Key Components*. http://www.northcoastrailroad.org/Agendas/2020/20200113/Memo_Item_E3.pdf?fbclid=IwAR3s6U5Fe9JSNurXX7T3njTfKeZtMflOyA5EvX-sEJVaoVy4f8RbDaGoUzw

GHD. (2021, March 17). *Sea Level Rise Adaptation Plan for Eureka Slough Hydrographic Area, Humboldt Bay*. https://humboldtgov.org/DocumentCenter/View/93857/SLR-Workshop-2-Slides?bidId=

Hossfeld, D. (2020, January 28). Retreat is not defeat. Retrieved April 12, 2021, from https://caseagrant.ucsd.edu/blogs/retreat-is-not-defeat

Humboldt County. (2021). Sea level rise. Retrieved April 12, 2021, from https://humboldtgov.org/2487/Sea-Level-Rise

Indiana University. (2021). Sea level rise. Retrieved April 12, 2021, from https://eri.iu.edu/erit/strategies/sea-level-rise.html

Kanjilal, Sahana. SaniFlavorverse. "7 of the Longest Bridges in the USA," December 26, 2017. https://flavorverse.com/longest-bridges-in-the-usa/.

Kopp, Robert E., Andrew C. Kemp, Klaus Bittermann, Benjamin P. Horton, Jeffrey P. Donnelly, W. Roland Gehrels, Carling C. Hay, Jerry X. Mitrovica, Eric D. Morrow, and Stefan Rahmstorf. "Temperature-Driven Global Sea-Level Variability in the Common Era." *Proceedings of the National Academy of Sciences* 113, no. 11 (March 15, 2016): E1434–41. https://doi.org/10.1073/pnas.1517056113.

Kraus, S., & Koch, N. (2021, February 18). Provisional COVID-19 infrastructure induces large, rapid increases in cycling. Retrieved April 13, 2021, from https://www.pnas.org/content/118/15/e2024399118

Laird, A. (2013, January). *Humboldt Bay—Mapping and SLR Vulnerability Assessment.* https://humboldtbay.org/sites/humboldtbay.org/files/Humboldt%20Bay%20-%20Mapping%20and%20SLR%20Vulnerability%20Assessment-A.Laird.pdf

Laird, A. (2018, January). Humboldt Bay Area Plan - Sea Level Rise Vulnerability Assessment. *Trinity Associates.* https://humboldtgov.org/DocumentCenter/View/62872/Humboldt-Bay-Area-Plan-Sea-Level-Rise-Vulnerability-Assessment-Report-PDF?bidId=

Ludwiszewski, R. B., & Haake, C. H. (2008). Cars, Carbon, and Climate Change. *Northwestern University Law Review, 102,* 665.

Miller, N. (2020, September 10). Travel - a new island of hope rising from the Indian Ocean. Retrieved April 12, 2021, from http://www.bbc.com/travel/story/20200909-a-new-island-of-hope-rising-from-the-indian-ocean

Moore, Robert. (2019, September 25th). "IPCC Report: Sea Level Rise Is a Present and Future Danger." NRDC. Accessed April 16, 2021. https://www.nrdc.org/experts/rob-moore/new-ipcc-report-sea-level-rise-challenges-are-growing.

NASA. (2014, June 12). 1St&2Nd laws of motion. Retrieved April 14, 2021, from https://www.grc.nasa.gov/www/k-12/WindTunnel/Activities/first2nd_lawsf_motion.html

NASA Sea Level Change Portal. "NASA Sea Level Change Portal: Thermal Expansion." Accessed April 5, 2021. https://sealevel.nasa.gov/understanding-sea-level/global-sea-level/thermal-expansion.

National Park Service. (2019, April 5). Seawalls, bulkheads, and Revetments (U.S. National PARK SERVICE). Retrieved April 12, 2021, from https://www.nps.gov/articles/seawalls-bulkheads-and-revetments.htm

National Oceanic and Atmospheric Administration. (n.d.). Living shorelines. Retrieved April 12, 2021, from https://www.habitatblueprint.noaa.gov/living-shorelines/

National Oceanic and Atmospheric Administration. (2014, March 01). How do coral reefs protect lives and property? Retrieved April 12, 2021, from https://oceanservice.noaa.gov/facts/coral_protect.html#:~:text=Corals%20form%20barrie

rs%20to%20protect,%2C%20property%20damage%2C%20and%20erosion.&text=Several%20million%20people%20live%20in,to%20or%20near%20coral%20reefs

O'Neill, C. R., Jr. (1986). Structural Methods for Controlling Coastal Erosion. Retrieved April 12, 2021, from https://seagrant.sunysb.edu/glcoastal/pdfs/StructuralMethodstoControlErosion.pdf

Oppenheimer, M., Glavovic, B., Hinkel, J., & Van der Wal, R. (2019, June 14). Chapter 4: Sea Level Rise and Implications for Low Lying Islands, Coasts and Communities. Retrieved April 12, 2021, from https://report.ipcc.ch/srocc/pdf/SROCC_FinalDraft_Chapter4.pdf

Patton, Jason R., et al. "Tectonic Land Level Changes and Their Contribution to Sea-Level Rise, Humboldt Bay Region, Northern California." *Cascadia Geosciences*, 2017. http://www.hbv.cascadiageo.org/HumBayVert/reports/USFWS/20170407/final_report_HBV_usfws_2017.pdf

Patten, P. (2016, July 21). Protecting Dunes: Connecticut beaches and Dunes: A hazard guide for coastal property owners. Retrieved April 12, 2021, from https://beachduneguide.uconn.edu/protecting-dunes/#

Satterfield, Dan. "Is There Something in the Water This Week?" *American Geophysical Union* May 17, 2018. https://blogs.agu.org/wildwildscience/2018/05/17/is-there-something-in-the-water-this-week/.

Schaeffer, M., Hare, W., Rahmstorf, S. et al. Long-term sea-level rise implied by 1.5 °C and 2 °C warming levels. Nature Clim Change 2, 867–870 (2012). https://doi.org/10.1038/nclimate1584

Schwedhelm, A., Li, W., Harms, L., & Adriazola-Steil, C. (2020, July 22). Biking provides a Critical Lifeline during THE CORONAVIRUS CRISIS. Retrieved April 14, 2021, from https://www.wri.org/blog/2020/04/coronavirus-biking-critical-in-cities

Stewart, Theodor J., Simon French, and Jesus Rios. "Integrating Multicriteria Decision Analysis and Scenario Planning—Review and Extension." *Omega* 41, no. 4 (August 1, 2013): 679–88. https://doi.org/10.1016/j.omega.2012.09.003.

Tracy, J. (2020, September 15). A cycling boom has materialized as a result of the coronavirus pandemic. Retrieved April 14, 2021, from https://www.axios.com/bikes-bicycles-sales-coronavirus-c5197e82-a8aa-4360-8989-65edb97427c6.html

U.S. Army Corps of Engineers. (1981, March). Revetments Their Applications and Limitations. Retrieved April 12, 2021, from https://apps.dtic.mil/dtic/tr/fulltext/u2/1003854.pdf

US Department of Commerce, National Oceanic and Atmospheric Administration. "Is Sea Level Rising?" Accessed April 5, 2021. https://oceanservice.noaa.gov/facts/sealevel.html.

US EPA, O. (2019). Sources of Greenhouse Gas Emissions [Overviews and Factsheets]. US EPA. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

Virginia Institute of Marine Science. (2017). Center for coastal resources management. Retrieved April 12, 2021, from http://ccrm.vims.edu/livingshorelines/design_options/offshore_breakwater.html

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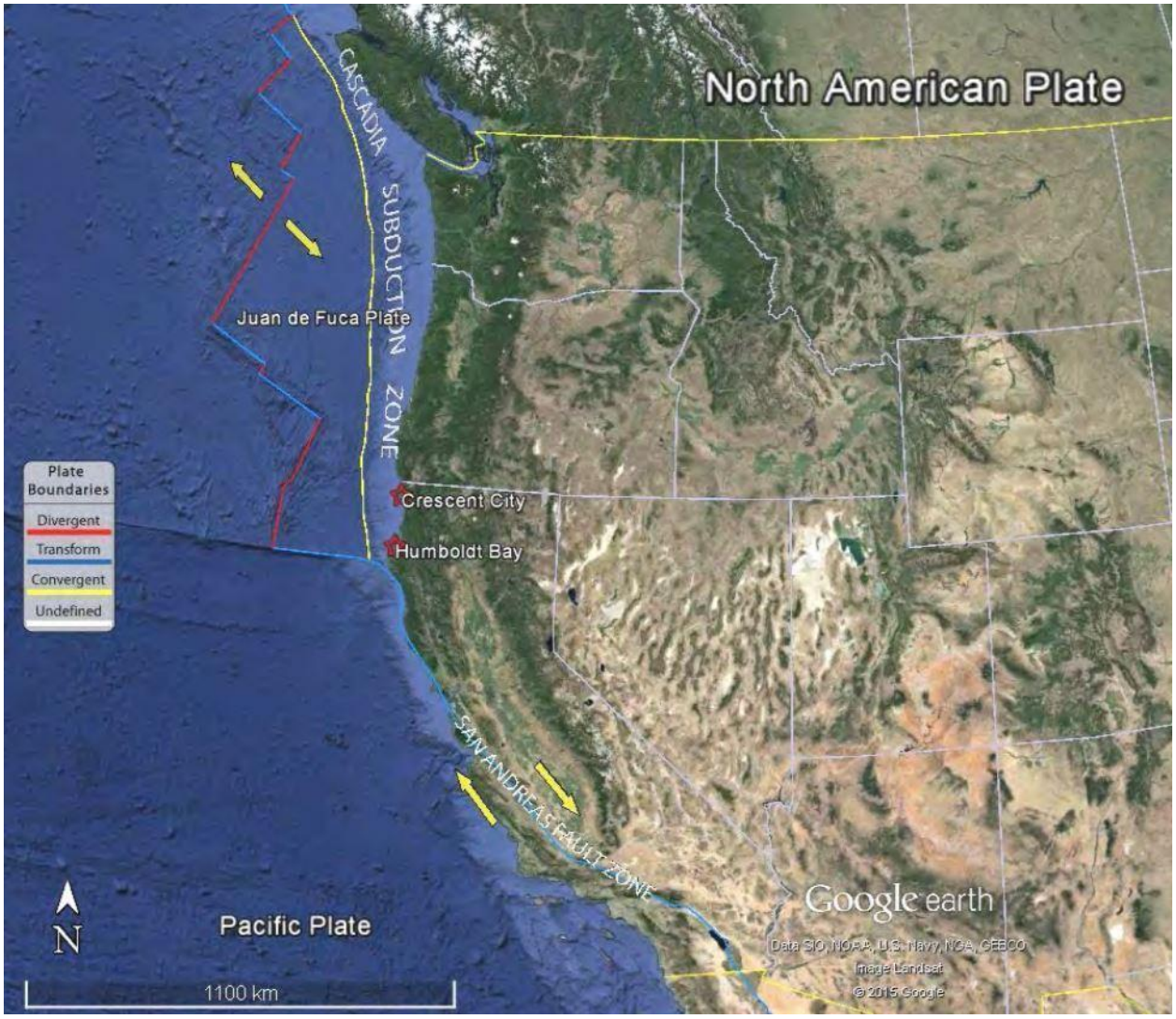
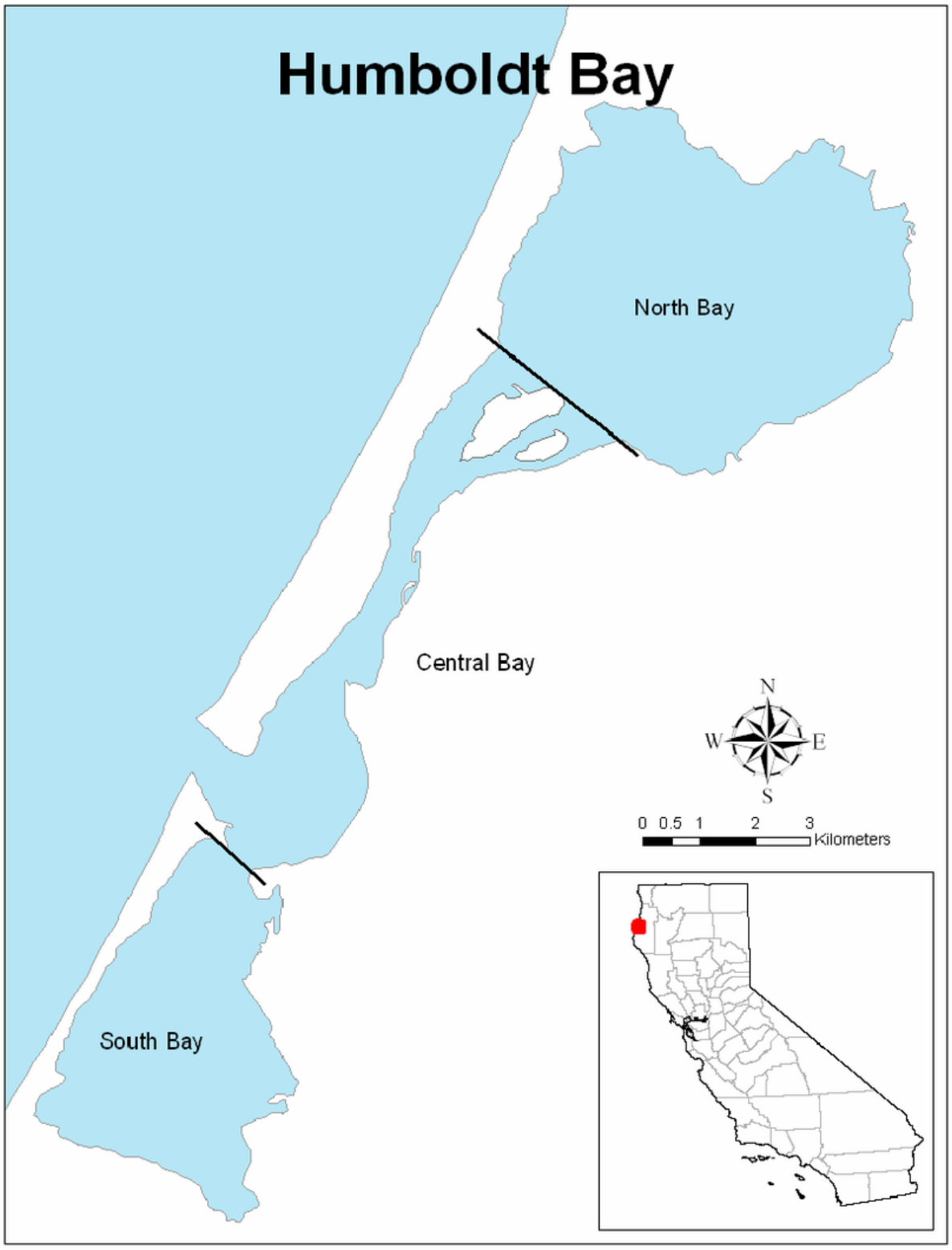
Appendix A: Cascadia Subduction Zone. Source: City of Arcata (2018)



Appendix B: Locator map of Humboldt Bay within California. Source: U.S. Fish and Wildlife Service (2005)



Appendix C: List of Interview Questions

- What adaptation measures are already being explored? How feasible are they?
- From your observations on SLR in Humboldt Bay, what approach(s) seems the most realistic?
- Has your committee communicated concerns or made any requests of Senator McGuire with regards to its connection to the Great Redwood Trail?
- Is there a way for us to access the maps and SLR projections used in public presentations?
- Do you consider the concept of induced demand when planning for multi-modal transportation?
- How will protective measures be implemented across jurisdictions?
- Would any prospective plans be open to including a multi-use pathway alongside the highway?
- Do you believe that any future projects should incorporate alternative transportation methods?
- California has ambitious climate goals, does a shift in transportation priorities play a role in that process?
- What is the most reliable or largest source of funding?
- Has your work led to any focus either on SLR or Trail development in Humboldt County?
- Do you support the development or protection of trails in the Humboldt Bay area?
- How does your organization support multimodal transportation improvement projects?
- Could there be options for extending this form of complete/streets or multimodal transportation to the HWY 101 corridor between Arcata and Eureka?
- Are there any gaps in collaboration or discussions that need to be filled before progressing forward?
- What have the proposals for protecting the City of Eureka from SLR looked like so far, have there been any?
- Are there any concerns or issues that you'd like to see addressed regarding the future of SLR and trail connectivity in this region?
- How do you interact with the other agencies implementing SLR adaptations/trail maintenance projects?
- How often do SLR projections need to be re-evaluated? Would you recommend basing projections on timelines or elevations?

Appendix D: Stakeholder Summary of Eureka-Arcata 101 Corridor. Source: Alvarez et. al (2020)

Stakeholder / Organization
Local Government
City of Eureka
City of Arcata
Humboldt Bay Harbor and Conservation District
Humboldt County Association of Governments
Humboldt County Department of Public Work
Humboldt County Resource Conservation District
North Coast Railroad Authority
Tribal Government
Bear River Band of Rohnerville Rancheria
Blue Lake Rancheria
Hoopa Tribe
Karuk Tribe
Native American Heritage Commission
Trinidad Rancheria
Wiyot Tribe
Yurok Tribe
State Government
California Coastal Commission
California Coastal Conservancy
California Department of Fish and Wildlife
California Department of Transportation
California Natural Resources Agency
California State Lands Commission
Department of Conservation

North Coast Regional Water Quality Control Board
Oceans Protection Council
State Office of Historic Preservation
Federal Government
National Oceanic and Atmospheric Administration
Natural Resources Conservation Service
U.S. Coast Guard
U.S. Army Corp of Engineers
U.S. Congressman Jared Huffman
U.S. Fish and Wildlife Service
Non-Governmental Organizations
Bigfoot Bicycle Club
Coalition for Responsible Transportation Priorities
Environmental Protection Information Center
Friends of Arcata Marsh
HSU Marine & Coastal Sciences Institute/ SLR Initiative
Humboldt Bay Bicycle Commuters Association
Humboldt Bay Initiative/Coastal Ecosystem Institute of Northern California
Humboldt Baykeeper
Humboldt State University Sea Level Rise Initiative
Humboldt Trails Council
Keep Eureka Beautiful
Northcoast Environmental Center
Northcoast Regional Land Trust
Pacific Coast Fish, Wildlife & Wetlands Restoration Association
Redwood Community Action Agency
Schatz Energy Resource Center

Trails Trust
Private Businesses
Alves Resale Lumber
Ayres Family Cremation
Bayside Garden Supplies
Berry RV Storage
Bobcat of Eureka
Bracut Business Park
California Trailers
Carl Johnson Hardware
Carl’s Furniture
Carlson Wireless Technologies
Coast Seafood
Coastline Foursquare Church
Don’s Rent All
Eureka Freightliner
Eureka Oxygen Company
Franz Bakery Outlet
Gas Stoves With Style
GHD
Gordon Engineering
Greenway Partners
Happy Dog DayCare and Boarding
Harper Motors
Hoff Outdoor Advertising
Hog Island
HT Harvey and Associates Consulting

Humboldt River Company
J’s RV Center
John’s Used Cars
Lazy J Trailer Ranch
Mid City Honda
Murray Airfield
Northern Hydrology & Engineering
Pacific Gas & Electric
Paper Material Handling
Pawlor
Point Blue Conservation Science
PWA/Cascadia Geosciences
Rainbow Self Storage
Rental Guys
Resale Lumber
Rogers Machinery Company
Simpson Lumber Company
Smart Foodservice Warehouse Stores
Taylor Mari Culture
Tea LAB
The Farm Store
U Haul
United Rentals