VULNERABILITY OF COMMUNITIES ENGAGED IN THE MARINE ECONOMY IN HAWAIʻI TO INUNDATION FROM SEA LEVEL RISE

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To Mele, Scott, Dylan, Kyle, and Mayali

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ABSTRACT

Global sea level is rising as a result of melting polar caps and thermal expansion of seawater, and estimates range from an increase of 0.5 to 1.4 meters in the next century. The impacts of sea level rise (SLR) may be more severe in some regions, with sea level in the Pacific rising at three times the global mean since 1993. The resilience and adaptation capacity of communities that may be potentially impacted by SLR is related to both physical and social vulnerability. Physical vulnerability of a community can be measured in part by the risk of inundation from SLR, while the social vulnerability can be quantified in part by an analysis of population data and potential economic loss, using an index of Community Social Vulnerability Indicator (CSVI) scores. In this study, communities, defined at the Census County Division (CCD) level that are engaged in three sectors (eight industries) that represent the marine economy in Hawai‘i are examined to compare relative risk of inundation from SLR. The potential economic loss from the marine economy in these eight industries was estimated from catch landings at each port. It was found that Honolulu CCD accounts for over 60 percent of the revenue from the nine industries in the marine economy included in this analysis: Honolulu CCD The resilience and adaptation capacity of Honolulu CCD may therefore be important statewide. Honolulu CCD has relatively low CSVI scores, indicating a stable community and perhaps relatively high adaptation capacity. However, Honolulu CCD also shows medium-high risk to inundation from SLR, which may destroy ports and other key infrastructure and contribute to economic loss.

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CCD……………………………………………………Census County Division
CSVI……………………….............Community Social Vulnerability Indicator
SLR…………………………………………………………Sea Level Rise

PREFACE

The aim of this project is to identify the communities most vulnerable to economic loss as a result of inundation from predicted sea level rise (SLR) in Hawai‘i. In an era with increased attention to climate change, there is a need to derive predictions to better understand the potential effects that climate change and its consequences will have on our communities. The state of Hawai‘i is highly dependent on the ocean for its sustenance and economy, and is therefore potentially vulnerable to economic loss from SLR as a result of global climate change that threatens communities engaged in fisheries (Nicholls and Cazenave, 2010; NOAA Fisheries, 2016).

While climate change is certainly a global issue, its effects are and will not be uniformly distributed (Farbotko and Lazrus, 2012; Nicholls and Cazenave, 2010; Titus, 1989). We therefore require more localized approaches to mitigation and resilience for an effective response (Cutter et al., 2003). This project attempts to understand the consequences of a global problem on specific communities. It explores the effects of SLR inundation, one consequence of global climate change, on communities in the state of Hawai‘i.

In an effort to recognize the ways in which a community’s socio-economic characteristics affect its ability to respond after a climatic disturbance (such as inundation due to SLR), this project integrates physical models of SLR with community-level demographic and State of Hawai‘i commercial fisheries data. This approach is intended to enhance understanding of how a community or localized population will experience the effects of global change relative to other communities.

Relative vulnerability is dependent on multiple factors, including community location and demographics (Kotowicz and Beavers, in press). Understanding which communities experience heightened relative vulnerability can be an important tool in allocating resources and funding to create effective management and adaptation strategies. Additionally, understanding the social and economic causes behind this increased vulnerability can also improve effectiveness of adaptation strategies by identifying target areas for improvement.

There is a need to understand the ways in which a community's demographics affect the ways that physical climate changes will manifest in each community to better understand specific local responses and design effective management strategies. It is the hope that studies like this may contribute to an increased understanding of the many factors that affect vulnerability by attempting to integrate multiple systems into a common measure of risk.

This research could help state and regional communities to prepare adaptation strategies to improve resiliency and decrease vulnerability, based on an understanding of distribution of revenue in the marine economy, social vulnerability indicators for each community, and potential SLR scenarios. Through an analysis of both population data coupled with predictions of inundation due to SLR, we hope to glean a better understanding of the ways in which climate changes in the next century could directly impact the people of Hawai‘i. In identifying the communities that are most vulnerable, these regions have a better chance to prepare, and therefore promote and protect the quality of life for its citizens.

CHAPTER 1: INTRODUCTION

As an isolated archipelago, Hawai‘i faces a growing need to predict the ways that sea level rise (SLR) as a result of global climate change will affect the entire state. Due to their direct reliance on marine resources in addition to the high concentration of infrastructure in coastal areas, communities with businesses engaged in the marine economy in Hawai‘i are particularly at risk of potential economic loss as a result of inundation due to SLR.

Additionally, the characteristics of those communities can help determine their ability to adapt to the changes and potential economic loss that will come in the next century. Understanding the ways that each community will be affected by SLR and the ways that they may respond can help build a picture of the ways that the entire state may be affected by the inundation experienced by several key communities.

Coastal communities engaged in the marine economy may experience the effects of SLR more acutely than their neighbors, and those with already vulnerable infrastructure, economies, or populations may experience a magnified vulnerability to the consequences of SLR (Kotowicz and Beavers, in press). The ways in which the societal structures in place dictate the magnitude, impact, and localization of physical effects are vital to management and resilience strategies (Cutter et al., 2003; Kotowicz and Beavers, in press).

Predicting economic loss helps to build a better picture of the ways that SLR and its related consequences could affect the state of Hawai‘i at the community level. Connecting projected SLR to losses in the marine economy provides a simple means of identifying communities that are at risk due to physical changes, and we are then able to investigate their socio-economic characteristics for an indication of ability to adapt in the event of such a disturbance.

1.1 Sea level rise

It is estimated that global sea level will rise between 0.18 and 0.48 meters by mid-century, and estimates range from 0.5 meter to as much as 1.4 meters by 2100 (IPCC, 2013). Sea level in the Pacific Ocean may increase by as much as 10 to 20 percent of the global mean by 2100 (Kane et al., 2014). It has been recognized for decades that atmospheric warming due to global climate change contributes to thermal expansion of seawater and loss of land ice, leading to global SLR (Titus, 1989; Nicholls and Cazenave, 2010; IPCC, 2013). The effects of SLR have global ramifications, though different regions are expected to experience consequences in varying degrees of severity (Abramovitz, 2002; Nicholls and Cazenave, 2010).

Satellite data show that sea level is not rising uniformly (Nicholls and Cazenave, 2010). The western Pacific, including Hawaiʻi and Oceania, has experienced SLR at rates up to three times faster than the global mean since 1993 (Nicholls and Cazenave, 2010). Small island states are at the most risk due to SLR as they are expected to experience the largest relative impacts (Nicholls and Cazenave, 2010), with some small island states in the Pacific, like Tuvalu or the Maldives, facing total submergence in the next century (Farbotko and Lazrus, 2012). While non-uniform distribution of the impacts of SLR puts islands at disproportionate risk, the relative vulnerability within these regions is also impacted by the population composition of these communities (Abramovitz, 2002; Cutter et al., 2003).

In Hawaiʻi, the risk of flooding has already increased from 1.7 to 15.9 percent in north Oʻahu) and 21.0 to 53.3 percent in south Māui (Kane et al., 2015). Recent estimates warn that that largest impacts from SLR will occur by 2050, meaning Hawaiʻi state officials have 37 years to develop and implement management action (Kane et al., 2015). Targeted management based on relative vulnerability may help increase the resilience of each community (Abramovitz, 2002).

1.2 Community vulnerability

Vulnerability of communities to hazards can be defined simply as the "potential for loss" (Cutter et al., 2003). While a relatively simple idea, measuring vulnerability can be complex. Vulnerability cannot be measured absolutely, but is rather understood as the vulnerability of one community relative to another. Similarly, it is temporally and spatially dynamic: Vulnerability of a specific community is subject to change depending on the geographic region, the climate, as well as political, economic, and social structure (Cutter et al., 2003). Therefore our approach to understanding vulnerability must include an attempt to understand the many variables that contribute to vulnerability and how their impacts intersect (Cutter et al., 2003).

Most studies in comparative vulnerability can be broadly separated into three categories (Cutter et al., 2003): (1) Identifying conditions that result in increased vulnerability to extreme weather events (Cutter et al., 2003), such as the increased vulnerability of islands in the Pacific to SLR due in part to a high percentage of total area in low-elevation coastal zones that are prone to inundation (Nicholls and Cazanave, 2010;

Kane et al., 2015); (2) studying the social characteristics of an environment under the assumption that vulnerability is a product of a society's resilience to or ability to adapt following an climatic anomaly or environmental hazard (Cutter et al., 2003; Abramovitz, 2002), such as the recognition of increased threats in regions that have rapid population growth combined with relatively low development (Nicholls and Cazanave, 2010); and (3) a localized study that attempts to understand the way a society will react to exposures either observed or modeled (Cutter et al., 2003).

The National Atmospheric and Oceanic Administration's (NOAA) (2010) strategic plan focuses on "resilient coastal communities" that respond to change in ways that minimize economic and social consequences (Jepson and Colburn, 2013). Jepson and Colburn (2013) define the relationship between vulnerability and resilience in fishing communities as "vulnerability being the immediate pre-disturbance state and resilience constituting the ability to cope post-disturbance over time." The documentation of actions and events after the initial disturbance can be used to evaluate resilience of coastal communities (Jepson and Colburn, 2013).

It can be challenging to measure vulnerability in a useful and practical way, and it is difficult to find a direct way to predict the way a community will respond to disturbances. Recent studies have suggested that the severity of climate change and extreme events on regional populations is not simply a direct result of the physical changes that can be predicted, but also significantly affected by political, economic, and social factors (Abramovitz, 2002; Farbotko and Lazrus, 2014). Therefore overall vulnerability has both physical and social components (Cutter et al., 2003). A more accurate understanding of community vulnerability must not only consider the physical changes that contribute to increased risk, but also the complex political, economic, and social interactions that increase (or in some cases counteract) overall community vulnerability.

Analysis of a community's social characteristics can give an indication of a more resilient community similarly to the ways that biological proxies can serve as indicators of the overall health of an ecosystem (Kotowicz and Beavers, in press). In 2010, NOAA Fisheries developed a suite of community social vulnerability indicators that can be used to help predict the vulnerability and resilience of communities in the United States to climatic disturbances, which were further developed for coastal fishing communities in the northeastern U.S. (Colburn et al., 2016) and adapted for use in Hawaiʻi (Kotowicz and Beavers, in press). These Community Social Vulnerability Indicators (CSVI) scores are calculated by analysis of publicly available census data and are available at multiple geographic levels, including Census County Division (CCD) boundaries, which define the communities examined here.

CSVI scores provide relative information about many different community characteristics. Jepson and Colburn (2013) developed the suite of indicators by collecting secondary population data and conducting factor analysis, a data reduction technique that allows the user to consolidate a large number of variables into an index of latent (i.e. not directly measurable) variables. This collapses a large number of statistics into underlying factors that can be more easily interpreted (Jepson and Colburn, 2013).

The CSVI indices used in this project, developed and defined by Jepson and Colburn (2013), are divided into seven indices: Personal Disruption; Population Composition; Poverty; Labor Force; Housing Characteristics; Housing Disruption; and

Retiree Migration.

Personal Disruption scores describe a community's ability to adapt or respond to change based on personal circumstances, including family life, such as marriage or children, or educational level, or any other variables that may increase probability that an individual will suffer from poverty and thus find it harder to adapt to change. It includes five variables: Percent unemployed, Crime index, Percent with no diploma, Percent in poverty, and Percent females separated, with percentage variance explained of 45 (Jepson and Colburn, 2013).

Population Composition describes population demographics and the relative percentage of socially vulnerable individuals in a community, including minorities, young children, female-headed householders, and those that do not speak English "very well". It includes four variables with a percentage variance explained of 58.12: Percent white alone, Percent female single headed households, Percent population age 0-5, and Percent that speak English less than well (Jepson and Colburn, 2013).

Poverty can be a powerful indicator of community vulnerability because high poverty generally corresponds well to high vulnerability. A high percentage of community members living in poverty could be due to educational levels, high unemployment, or numerous other factors, and generally makes it more difficult for a community to access the resources to return to the initial state after a disturbance. It includes four variables with 59.72 percentage variance explained: Percent receiving assistance, Percent of families below poverty level, Percent over 65 in poverty, and Percent under 18 in poverty (Jepson and Colburn, 2013).

Labor Force scores characterize the strength of a community's labor force. If a community exhibits high risk in the Labor Force category, that could indicate low employment opportunities and thus a more vulnerable population, as a highly specialized economy with little other employment opportunities renders a community highly vulnerable to economic disturbance and community members may have difficulty finding work elsewhere. It consists of four variables with 65.25 variance explained: Percent females employed, Percent population in the workforce, Percent of class of worker self employed, and Percent population receiving social security (Jepson and Colburn, 2013).

Housing Characteristics scores indicate the vulnerability of a community's infrastructure. Coastal communities with valuable infrastructure located on or near a coastline may be more vulnerable to coastal hazards and thus experience higher community vulnerability. However, some interpret affordable housing to be an indicator of lower community vulnerability as it may counteract some of the risk associated with a high percentage of community members living in poverty. It consists of four variables with 60.60 variance explained: Median rent in dollars, Median mortgage in dollars, Median number of rooms, and Percent mobile homes (Jepson and Colburn, 2013).

Housing Disruption is an economic indicator that characterizes a community's housing market. A fluctuating housing market could indicate risk of displacement due to rising home values, mortgage payments, or rents. A community with high Housing Disruption risk may be particularly vulnerable to gentrification and rising cost of living. This is particularly significant in a state like Hawaiʻi, with already relative high cost of living and limited space that may be threatened by sea level rise. It consists of three variables with a 53.00 percentage variance explained: Percent change in mortgage, Percent change in home values, and Percent of owners' monthly costs that make up 35% or more of their income (Jepson and Colburn, 2013).

Retiree Migration is included in the gentrification indices for community vulnerability and indicates a community with a high concentration of retirees or elderly people. A high Retiree Migration score could also indicate vulnerability to gentrification as retirees often move to coastal communities and seek comfortable amenities, contributing to an increased cost of living and possibly leading to the displacement of other community members. Additionally, a large population of retired community members may contribute to economic vulnerability or higher Labor Force risk due to a smaller work force. It consists of four variables with a 78.59 percentage variance explained: Households with one or more over 65, Percent population receiving social security, Percent receiving retirement income; and Percent in labor force (Jepson and Colburn, 2013).

1.3 Fishing and the marine economy in Hawai'i

The state of Hawai'i continues to depend on seafood as a major source of protein, though the exploitation of marine resources has changed as the marine economy expanded. In 2014, Hawai'i's seafood industry generated $742 million in sales impacts in addition to $336 million in value-added impacts, and employs approximately 10,000 individuals in both full and part-time jobs (NMFS, 2016).

The entire marine economy employs 503,000 individuals in full and part-time positions statewide, well above the national baseline (NMFS, 2016). NOAA utilizes a Commercial Fishing Location Quotient (CFLQ) that compares the proportional size of a regional marine economy to the national average, defined as 1. In 2013, the CFLQ in Hawai‘i was 4.44, suggesting that employment in the marine economy in Hawai‘i is 4.44 times higher than the national average (NMFS, 2016).

This project focuses only on a small sub-section of the marine economy, due to data availability. Businesses are defined here as engaged in the marine economy if they are classified in three industries with eight smaller sub-sectors, based on North American Industry Classification System (NAICS) categorization: Fishing, which contains finfish fishing, shellfish fishing, other marine fishing; Aquaculture, which includes finfish farming and other hatcheries; shellfish farming, and other aquaculture; and Seafood Commerce, which includes fish and seafood markets and seafood product preparation and packaging (Colburn et al., 2016).

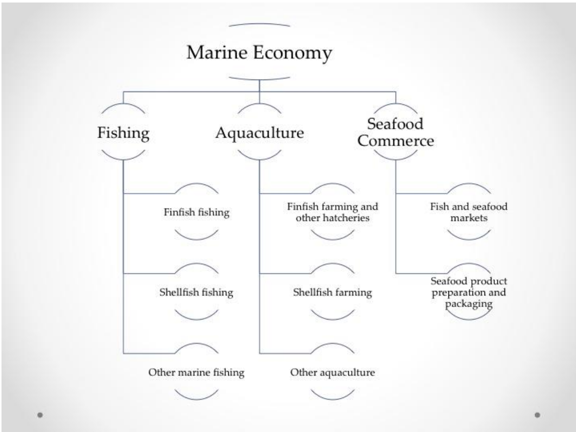

Figure 1.1 The three industries and sub-sectors of the marine economy as defined in this project.

The businesses identified using NAICS codes provide limited insight into the distribution of revenue in the marine economy, because they represent an incomplete picture of the statewide engagement in the marine economy. However, despite its narrow scope, the analysis of a subsector of the economy can be useful for investigating the impacts of sea level rise on communities with relatively large revenue.

The diversity of businesses in the community economy can also affect the relative severity of impacts from SLR or other climatic disturbances; an economy heavily reliant on marine resources with few employment opportunities elsewhere is likely to find it more difficult to recover from potential disturbances to fishing or related businesses due to SLR. Management can affect community vulnerability both positively and negatively through allocation of resources to improve community resilience or fisheries management policies that limit catch, gear, fishery entry, or other fishing effort.

Ocean changes associated with global climate change may change the migration and spawning patterns of target species, which could have either positive or negative effects on fishermen (Colburn et al., 2013). Furthermore, changes in management in addition to changes due to SLR can make it difficult for fishermen and fishing communities to predict their catch in the upcoming years, causing stress and decreasing overall quality of life (Pollnac et al., 2015).

Overall community vulnerability is therefore a product of physical vulnerability and social vulnerability. Physical vulnerability is measured here as relative risk due to sea level rise (SLR), while social vulnerability is measured here by the community characteristics that determine how a community may react to the changes and impacts from SLR, or social vulnerability, and quantified here using Community Social Vulnerability Indicators (CSVI scores).

1.4 Cultural Background

Local (recreational) fisheries are declining in their importance to the marine economy and as a source of sustenance and income in Hawaiʻi but remain an integral part of cultural tradition (Kirch, 1982). Participation in recreational fishing is declining: From 2013 to 2014, there was a 9 percent decrease in the number of recreational fishing trips taken from Hawaiʻi, employing approximately 1,061 individuals in full and part-time positions (NMFS, 2016). Native Hawaiians traditionally employed a diverse range of methods in the exploitation of the marine environment, a reflection of their dependence on marine life as their dominant source of protein (Kirch, 1982).

Traditional fishing methods are rarely employed in Hawaiʻi today, except recreationally and by a small number of subsistence fishermen (Friedlander et al., 2013). Despite significant changes in fisheries management and equipment in the modern era, the knowledge and practice have persisted and are experiencing resurgence in some cases (Friedlander et al., 2013).

The return to community-based management system, particularly those that employ traditional fishing methods, is gaining traction in the state of Hawaiʻi and some believe this trend may towards a more local management system will improve the condition of Hawaiʻi's coastal marine environment (Friedlander et al., 2013). This may increase the resilience of communities engaged in the marine economy to changes due to SLR.

CCDs were chosen as the primary geographic level of focus for this project because of their practicality, particularly for employing CSVI scores calculated primarily from available census data, but also because of their close alignment with traditional Hawaiian *ahupuaʻa* (mountain-to-sea agricultural and political land divisions) and *moku* (island) boundaries (Kotowicz and Beavers, in press).

This connection between modern political land divisions and traditional Hawaiian systems is important because the reemergence of Native Hawaiian land-management practices and cultural traditions has been shown to increase community and individual well-being (Friedlander et al., 2013). This suggests that resurgences in cultural practices and values may contribute positively to community well-being, and therefore have a negative effect on vulnerability (Cutter et al., 2003; Friedlander et al., 2013).

CHAPTER 2: METHODS

This project applies mixed methodologies in an interdisciplinary framework in an effort to better understand community vulnerability to SLR in Hawai‘i. In an attempt to understand the relationship between physical and social disruption that a community may be vulnerable to, this project focuses on understanding the potential economic loss that communities engaged in the marine economy in Hawai‘i face as a result of projected SLR in the next century. It uses model data of expected inundation due to SLR in the state of Hawai‘i to identify which businesses are most physically vulnerable. Then the social vulnerability of the communities that these businesses are registered in is identified using Community Social Vulnerability Indicator (CSVI) scores. This identifies communities that are experiencing physical vulnerability from potential inundation as well as estimates their social vulnerability that may help predict a community's ability to cope with those changes.

2.1 Identifying businesses engaged in the marine economy

The first part of this project identifies businesses engaged in the marine economy and the distribution of revenue along various geographic scales. The U.S. Census Bureau's municipal boundaries for Census County Divisions (CCDs) are the primary region of focus in this project, though there is some analysis by island and county. County boundaries align with islands except in the case of Māui County, which includes Māui Island, Moloka‘i Island, Lana‘i Island and Kaua‘i County, which include Kaua‘i Island and Ni‘ihau Island, though few data are available for Ni‘ihau. The eight major islands in the State of Hawai‘i are divided into 44 CCDs, with areas ranging from 4 to 487 square kilometers.

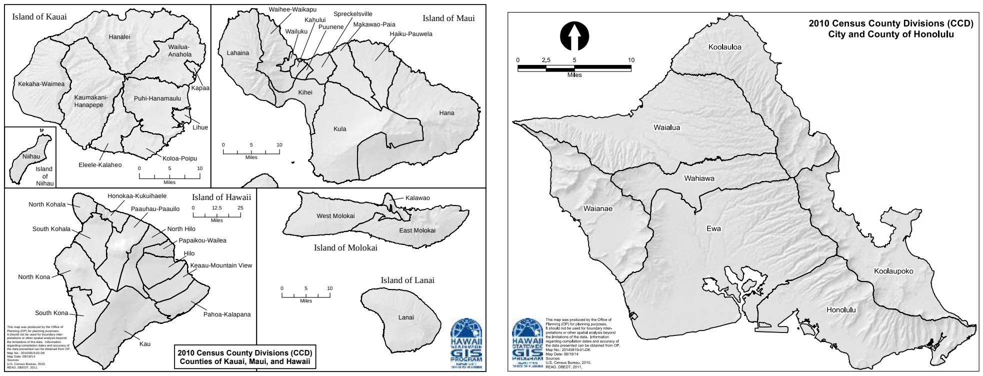

Figure 2.1 CCD boundaries on the major Hawaiian Islands (from State of Hawaii Office of Planning).

Both the federal and state government as well as private data compilation services, like ESRI, employ the North American Industry Classification System (NAICS), which assigns codes to each business based on industry. These NAICS codes were sed to identify businesses engaged in one of the eight industries of interest in this project (adapted from Colburn et al., 2016) (Table 2.1). However, identifying businesses engaged in the marine economy by NAICS codes provides limited insight because it does not include all businesses. There is a significant disparity between the annual revenue reported from the marine economy (NMFS, 2016) and the totals calculated from the businesses identified here. This forces an analysis

Industry	**NAICS Code**
Finfish farming and fish hatcheries	112511
Shellfish farming	112512
Other aquaculture	112519
Finfish fishing	114111
Shellfish fishing	114112
Other marine fishing	114119
Seafood product preparation and packaging	311710
Fish and seafood markets	445220

Table 2.1. Industries in the defined marine economy and associated NAICS codes (from Colburn et al., 2016).

of only a small subsection of the marine economy for some parts of this project. This limited scope will be referred to as the "limited marine economy" or the "marine economy (as identified here)" throughout this paper for clarity.

Based on data availability, the marine economy is defined in this project to be composed of three different industries, Fishing, which contains finfish fishing, shellfish fishing, other marine fishing; Aquaculture, which includes finfish farming and other hatcheries; shellfish farming, and other aquaculture; and Seafood Commerce, which includes fish and seafood markets and seafood product preparation and packaging (Colburn et al., 2016).

The ESRI business database (2013) lists businesses in Hawai'i, their annual reported revenue, number of employees, and coordinates. Once businesses were identified as engaged in the marine economy using NAICS codes, they were aggregated by CCD by plotting their coordinates on a shapefile that was overlaid with CCD boundary shapefiles using ArcGIS Desktop™ software.

2.2 Community Social Vulnerability Indicators

Data were compiled at the Census County Division (CCD) level to calculate a Community Social Vulnerability Indicator (CSVI) score for each community. Demographic data from each of these CCDs can be found through the U.S. Census Bureau's American Community Survey (ACS) datasets, with data for this project primary found in the ACS databases from 2009-2013. The variables and methods for calculating CSVI scores used in this project were developed by Jepson and Colburn (2013) and adapted for use in Hawai‘i by NOAA’s Pacific Islands Fisheries Center (Kotowicz and Beavers, in press).

The variables from data collected in the ACS database served as inputs in identifying latent variables to serve as broad vulnerability indices or categories. The factor analysis process employed consisted of a principle component analysis and a varimax rotation, which allows the user to determine which variables have the highest loading on a factor (Jepson and Colburn, 2013). Indices were retained if a single factor solution was achieved and met all criteria and significance thresholds (the same used to determine SLR risk indicators), including a total variance explained above .450; the Kaiser-Meyer-Olkin measure of sampling adequacy above .500; factor loadings all above .350; and Bartlett’s test of sphericity significance above .05 (Jepson and Colburn, 2013) (Appendix B).

Seven indices were determined to describe community social vulnerability: Personal Disruption; Population Composition; Poverty; Labor Force; Housing Characteristics; Housing Disruption; and Retiree Migration (Jepson and Colburn, 2013). Each CCD was assigned a relative score from 1 to 4, with a score of 1 indicating low relative risk, a score of 2 indicating medium-low relative risk, a score of 3 indicating medium-high risk, and a score of 4 indicating high relative risk.

2.3 Sea level rise risk indices

The same methodology that Colburn et al. (2016) used to determine SLR risk indices for communities on the U.S. Eastern and Gulf Coasts was used to develop risk factors to estimate the threat of inundation to each community in Hawai‘i. Using coastal elevation data from NOAA Office for Coastal Management, total land area with land elevations between one and six feet above mean higher high water was computed. The area of potential SLR impacts was computed by overlapping the land area along CCD boundaries with the NOAA elevation shapefiles from one to six feet of predicted SLR using ArcGIS Desktop™ software (Colburn et al., 2016).

Once businesses were identified as engaged in the (limited) marine economy and aggregated by CCD, they were overlaid with SLR projections to identify which communities may be most vulnerable to inundation. All variables of potential land area lost were used as inputs in a principal component analysis with a single factor solution to meet the following criteria: a minimum variance explained of 45%; Kaiser-Meyer-Olkin measure of sampling adequacy above .500; factor loadings above .350; Bartlett's test of sphericity significance above .05; and an Armor's Theta reliability coefficient above .500 (Colburn et al., 2016). Factor loadings were then ranked into four categories of vulnerability, assigned to each CCD: 1 (low risk), 2 (medium-low risk), 3 (medium-high risk), and 4 (high risk) (Colburn et al., 2016).

2.3 Estimating potential seafood supply lost

Fisheries catch and revenue data are compiled by National Marine Fisheries Service (NMFS) (2016) as well as additional studies by Loke et al. (2012) and represent reported catch from the State of Hawai'i Commercial Marine License Holders. Revenues come from the State of Hawai'i Marine Dealer Database. These data are organized by landing port and each port was assigned to its CCD to indicate in which community the catch is landed. Total annual catch was averaged over a five year period between 2009 and 2013, and the average annual catch for each CCD that exhibited medium-low, medium-high, or high risk in addition to a positive inundation factor was measured and used to estimate potential catch loss due to SLR for the state in the next century.

CHAPTER 3: RESULTS

Honolulu CCD contributes the highest percentage of total revenue from the marine economy and highest percentage of catch landed from 2009-2013, and exhibits relatively high risk to SLR. Since Honolulu is also the most densely populated CCD, its vulnerability is significant statewide as economic decline or collapse following climatic disturbances will likely affect the whole state economy.

3.1 Distribution of revenue in the marine economy

The state marine economy directly employs 10,000 individuals in full and part-time positions and generated over $101 million from the commercial harvest in 2014 (NMFS, 2016). Using the ESRI State of Hawai‘i Marine Economy (2013) database, which provides limited insights into the individual fishing enterprises, the industries investigated in this analysis employ 457 individuals in 109 registered businesses and accounted for $55 million in revenue in 2010 (Table 3.1).

Businesses identified through the ESRI database engaged in the fishing industry, which includes finfish fishing, shellfish fishing, and other marine fishing, directly employ 74 individuals in 24 registered businesses and reported over $7 million in revenue in 2010. Due to lack of data availability, this does not include the Hawai‘i Longline Fishery, which accounted for an additional $90 million in annual revenue in 1997 (Loke et al., 2016).

Aquaculture is a growing and lucrative sector of the marine economy. Businesses engaged in aquaculture industries, as defined using the ESRI (2013) database, generated $14,975,500 in annual revenue and employed 195 individuals in 39 businesses. This is an underestimate: Locally generated reports indicate finfish and shellfish aquaculture generated $4,867,000 in 2009, while algae production generated $17 million and is not entirely accounted for in the businesses identified using the ESRI (2013) database (Loke et al, 2016).

Despite the importance of aquaculture, the marine economy (as defined here), the seafood commerce industry remains the most lucrative, employing 186 individuals and accounting for $32 million in revenue in 2010.

Industry	**Number of businesses engaged**	**Number employed**	**Revenue**
Fishing			
Finfish fishing	3	5	$625,000
Shellfish fishing	11	33	$3,032,000
Other marine fishing	11	38	$4,018,000
Fishing total	24	76	$7,675,000
Aquaculture			
Finfish farming and fish hatcheries	23	126	$9,219,000
Shellfish farming	4	23	$1,840,000
Other aquaculture	12	46	$3,916,500
Aquaculture total	39	195	$14,975,000
Seafood commerce			
Fish and seafood markets	40	121	$18,580,666
Seafood product preparation and packaging	6	65	$13,885,909
Commerce totals	46	186	$32,466,575
State totals	109	457	$55,117,075

Table 3.1 Number of businesses, employees, and total revenue from each industry in the limited marine economy.

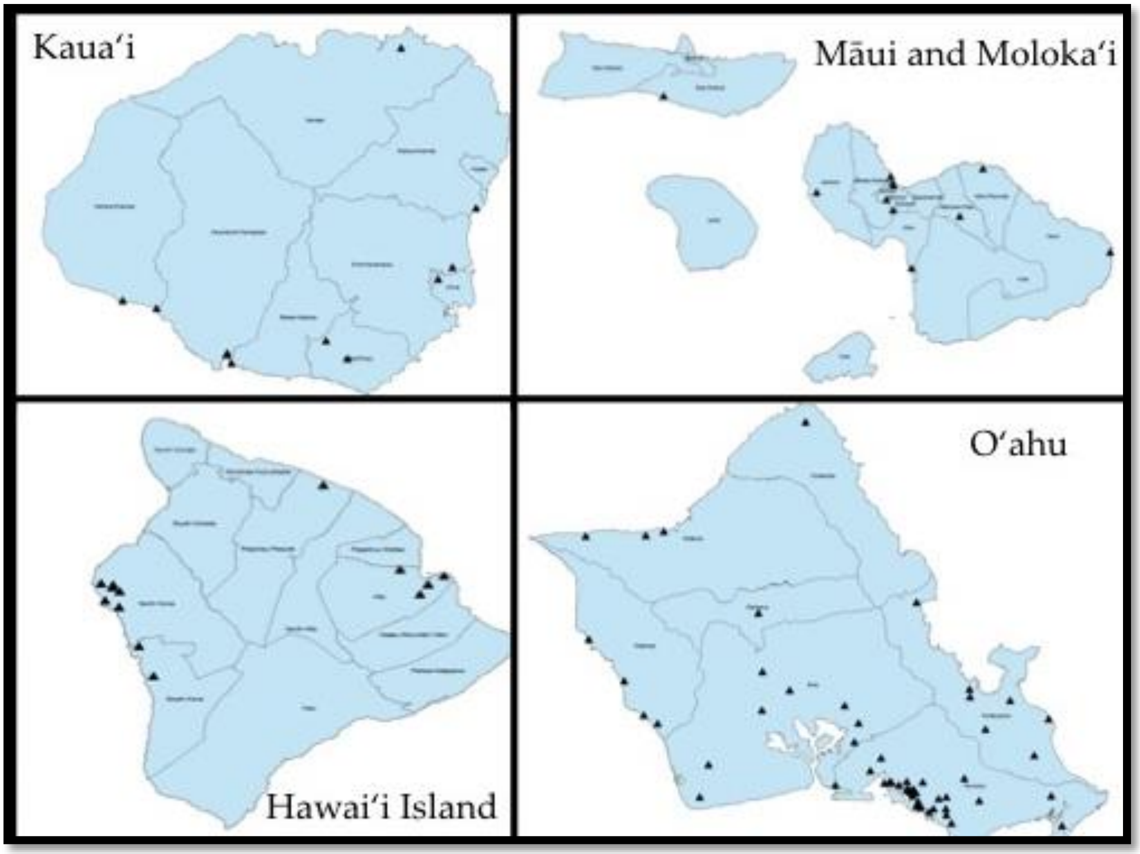

Figure 3.1 Businesses engaged in the limited marine economy by CCD.

The 109 businesses engaged in the limited marine economy identified by the ESRI (2013) database are contained in a total of 24 Census County Divisions (CCDs). The total revenue is overwhelmingly concentrated in two CCDs: North Kona CCD on Hawai'i Island, and Honolulu CCD on O'ahu, which combined account for nearly 72 percent of total revenue identified here. Honolulu CCD alone accounts for over 60 percent of the total revenue identified here (Table 3.2).

Similarly to the concentration of revenue in two CCDs, the revenue is also overwhelming concentrated by county. O'ahu accounts for nearly 75 percent of revenue from the limited marine economy, and O'ahu and Hawai'i Island combined account for almost 90 percent of state revenue from the limited marine economy (Table 3.3). CCDs on

O‘ahu Island contribute the highest percentage of reported revenue in each industry of the limited marine economy that they are engaged in.

CCD	Island	Revenue	Percent of State Total
Honolulu	O'ahu	$33,279,575	60.38
North Kona	Hawai'i	$6,396,000	11.60
Ewa	O'ahu	$2,310,000	4.19
Koolaupoko	O'ahu	$2,094,500	3.80
Kekaha-Waimea	Kaua'i	$1,945,000	3.53
Koolauloa	O'ahu	$1,449,000	2.63
Wailuku	Māui	$1,160,000	2.10
Hilo	Hawai'i	$1,043,000	1.89
Kaumakani-Hanapepe	Kaua'i	$970,000	1.76
Waialua	O'ahu	$648,000	1.18
Lihue	Kaua'i	$443,000	0.80
Waianae	O'ahu	$438,010	0.79
Koloa-Poipu	Kaua'i	$379,000	0.69
South Kona	Hawai'i	$360,000	0.65
Kihei	Māui	$350,000	0.64
Makawao-Paia	Māui	$310,000	0.56
Eleele-Kalaheo	Kaua'i	$240,000	0.44
Wahiawa	O'ahu	$220,000	0.40
Hanalei	Kaua'i	$210,000	0.38
Paauhau-Paauilo	Hawai'i	$190,000	0.34
Lahaina	Māui	$190,000	0.34
East Moloka'i	Moloka'i	$190,000	0.34
Kapaa	Kaua'i	$120,000	0.22
Hana	Māui	$110,000	0.20
Haiku-Pawela	Māui	$72,000	0.13

Table 3.2. Revenue from businesses engaged in the marine economy as defined by NAICS, aggregated by CCD with total revenue and revenue as a percentage of total.

Fish and seafood markets are the most common industry (the largest number of CCDs are directly involved in this industry), and support the largest number of employees in this limited analysis. Fish and seafood markets are present on all major islands: Hawai‘i Island, Māui, O‘ahu, and Kaua‘i all support multiple businesses involved in fish and seafood markets. Fish and seafood markets often rely on both locally caught seafood as well as imported seafood (Loke et al., 2016).

The distribution of revenue in the marine economy is far from even, with a high concentration of revenue from the representative marine economy in two CCDs: Honolulu CCD on O‘ahu and North Kona CCD on Hawai‘i Island. Within these CCDs, there are businesses from several different sectors and industries.

County	Total Revenue	Percent of State Revenue
O’ahu	$40,439,075	74.78
Hawai’i	$7,989,000	14.54
Kaua’i	$4,307,000	7.85
Māui	$2,382,000	4.40
STATE TOTAL	$55,117,075	100

Table 3.3: Revenue from the limited marine economy by island and as a percentage of the total.

3.2 Community social vulnerability indicator scores

Overall, the state of Hawai‘i exhibits low-risk in most of indicators of social vulnerability used in this project. Indicator categories with the highest risk for CCDs with businesses engaged in the marine economy are *Housing Disruption* and *Retiree Migration*, both exhibiting between medium-low (2) and medium-high risk (3).

Most of the CCDs that constitute the largest share of revenue from the limited marine economy also have fairly low CSVI scores, indicating relatively low social vulnerability in those communities. Honolulu CCD, which accounts for over 60 percent of total revenue generated by the marine economy as identified here, is only above the national average CSVI score for one indicator, *Population Composition*, and that difference is slight (0.2) (Table 3.5).

56 percent of CCDs with businesses engaged in the limited marine economy exhibit low-risk in CSVI scores for *Poverty*, similar to 53 percent of CCDs without businesses engaged in the limited marine economy. However, only 1 CCD with businesses engaged in the limited marine economy exhibit high risk of *Poverty*, while 12.5 percent of CCDs without businesses engaged in the limited marine economy exhibit high risk.

CCD	Percent of MER	PD	PC	POV	LF	HC	HD	RM
Honolulu	60.38	1	3	1	1	1	1	2
North Kona	11.60	2	2	2	1	2	3	1
Ewa	4.19	1	4	1	1	1	1	1
Koolaupoko	3.80	1	3	1	1	1	2	2
Kekaha-Waimea	3.53	1	3	1	2	1	3	2
Koolauloa	2.63	1	2	1	1	1	4	1
Wailuku	2.10	1	3	1	1	1	3	1
Hilo	1.89	1	3	2	2	2	1	2
Kaumakani-Hanapepe	1.76	1	3	1	1	3	2	1
Waialua	1.18	1	3	1	1	1	4	1
State average		1.2	2.8	1.6	1.2	1.5	2.5	1.5

Table 3.4 CSVI scores for 10 highest-earning CCDs in state. PD refers to *Personal Disruption*; PC to *Population Composition*; POV to *Poverty*; LF to *Labor Force*; HC to *Housing Characteristics*; HD to *Housing Disruption*; and RM to *Retiree Migration*. A score of 1 corresponds to a low risk; 2 to a medium-low risk; 3 to a medium-high risk; and 4 to a high risk.

88 percent of CCDs with businesses engaged in the limited marine economy identified here show low-risk or medium-low risk in *Housing Characteristics* CSVI scores, compared to 37 percent of CCDs without businesses engaged in the limited marine economy as identified here that exhibit low risk in *Housing Characteristics* indicators, while 6.25 percent exhibit high risk.

17 percent of CCDs without businesses engaged in the limited marine economy identified here exhibit medium-high risk in *Personal Disruption*, and an additional 17 percent exhibit medium-low risk. The 88 percent of CCDs with businesses engaged in the limited marine economy identified here exhibit low risk in *Personal Disruption* CSVI scores, and an additional 8 percent exhibit medium-low risk.

20 percent of CCDs with businesses engaged in the limited marine economy identified here exhibit low risk compared to 59 percent of CCDs without businesses engaged in the limited marine economy identified here in *Labor Force* characteristics. 80 percent of businesses engaged in the limited marine economy exhibit medium-low risk, while 35 percent of communities engaged in the limited marine economy exhibit medium-low risk or above.

A comparison between CCDs with communities engaged in the marine economy identified here, compared to CCDs without businesses engaged in the marine economy identified here, reveals lower risk in communities that are engaged in the marine economy identified here in four categories: *Poverty*, *Housing Characteristics*, *Labor Force*, and *Personal Disruption* (Appendix A).

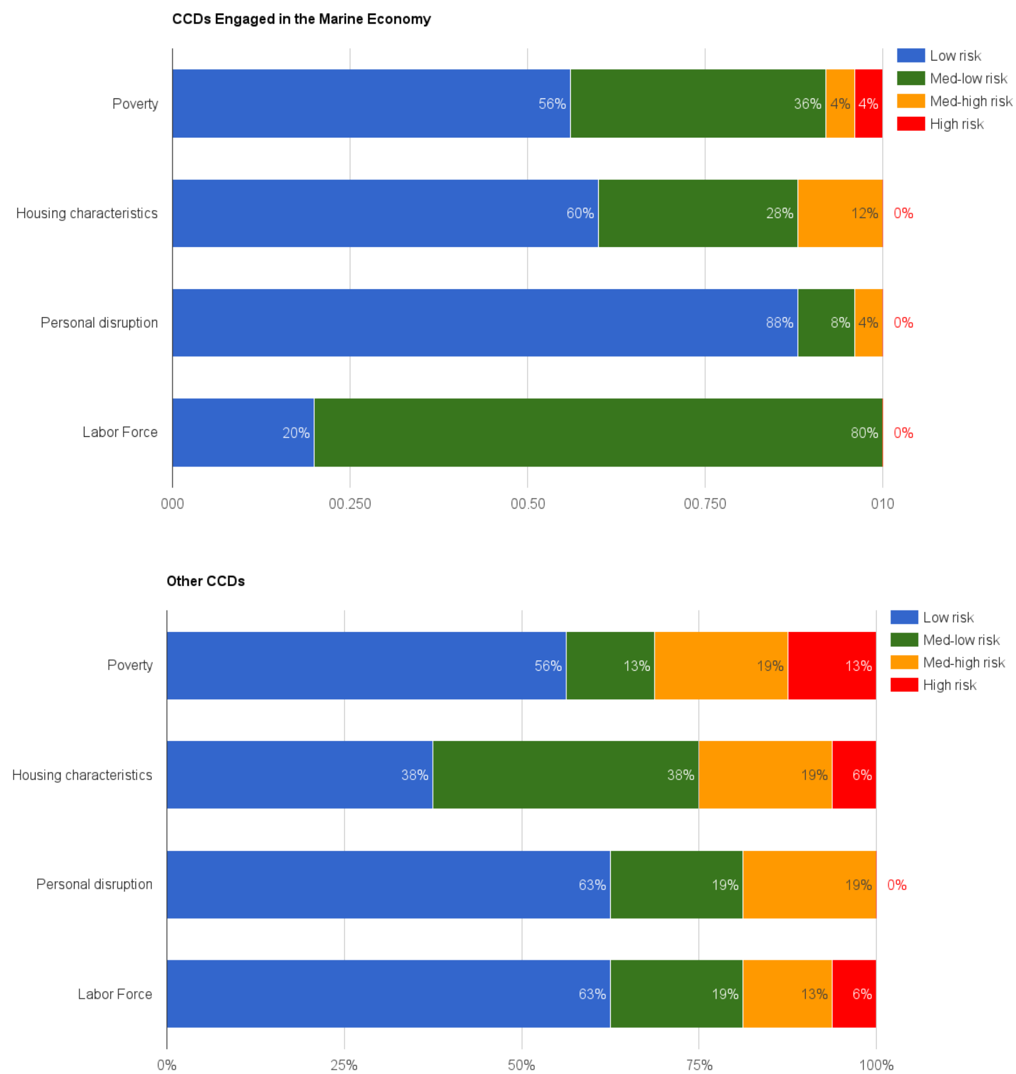

Figure 3.2 A comparison between percentage of CCDs with businesses engaged in the marine economy and other CCDs on low, medium-low, medium-high, and high risk in four different vulnerability indicators: Poverty, Housing Characteristics, Personal Disruption, and Labor Force.

3.3 Communities affected by potential sea level rise

Communities on the west coasts of the islands appear to experience higher risk of sea level rise, with Kekaha-Waimea CCD, on the northwest coast of Kauaʻi and Honolulu CCD, on the southwest coast of Oʻahu experiencing the highest risk due to inundation from SLR (Figure 3.1). There are seven businesses that exhibit high or medium high risk of inundation due to SLR including Kekaha-Waimea and Honolulu CCD, which also comprises the largest percentage of revenue from the marine economy and highest percentage of pounds landed.

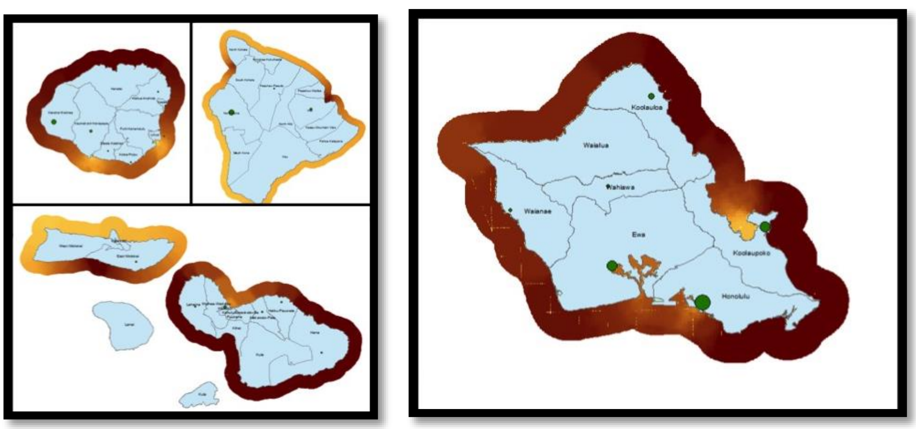

Figure 3.3. A map of the archipelago showing relative size of revenue and risk of inundation due to SLR by CCD. The size of the green circles indicates relative revenue by CCD, and the color of the border identifies SLR risk; red represents highest risk while yellows represent relatively low risk.

In 2014, commercial fishermen in Hawaiʻi landed more than 33 million pounds of finfish and shellfish, with tuna caught from the Hawaiʻi Longline Fishery accounting for over 73 percent of the landings revenue and 61 percent of the landed weight (NMFS, 2016).

There are 7 CCDs engaged in the marine economy that exhibit medium-high to high risk of vulnerability to SLR. CCDs with medium high or high SLR risk have an average per capita pounds landed of 26.1 pounds per person living in CCD, wile CCDs with low or medium low SLR have average per capita pounds landed of 12.9 pounds per person living in CCD. Four of seven CCDs with medium high or high SLR risk have more fishermen per 1000 people in CCD population than the state average of 1.6 fishermen per 1000 people in population.

CCD	Island	SLR risk index	CCD population	Total catch (lbs) from ports in CCD	Average Number of commercially-licensed fishermen that live in CCD	Pounds landed per capita population (total population in CCD)	Fishermen per 1000 people in CCD population
Kekaha-Waimea	Kauai	High	5091	142,814	51	28.1	10.0
Honolulu	Oahu	Medium- High	394239	22,131,466	537	56.1	1.4
East Molokai	Molokai	Medium- High	4232	40,670	34	9.6	8.0
Ewa	Oahu	Medium- High	329637	73,672	70	0.2	0.2
Koolaupoko	Oahu	Medium- High	117512	461,485	278	3.9	2.4
Hanalei	Kauai	Medium- High	7593	42,375	59	5.6	7.8
Koolauloa	Oahu	Medium- High	20452	15,871	19	0.8	0.9
Kihei	Maui	Medium-Low	24594	206,302	210	8.4	8.5
North Kona	Hawaii	Medium-Low	40823	1,385,911	616	33.9	15.1

Table 3.5 Risk of inundation and SLR index by CCD with number of ports, average number of fishermen, and average annual catch in pounds from 2009-2013.

Between 2009-2013, there was an average of 2272 commercially licensed fishermen in the state, with an annual average of 28,099,249 pounds landed. The majority of seafood supply comes from the Hawaiʻi Longline Fishery (the tuna and swordfish fleet), comprising an annual average 21.02 million pounds, while the non-longline catch accounts for an average of 7.07 million pounds landed annually. 81.5 percent of total average annual pounds caught in the State of Hawaiʻi are landed in ports that are at medium-high or high risk to SLR inundation, and 36 percent of these commercial fishers live in CCDs with medium-high or high SLR risk.

CCD	Island	SLR index	Number of ports in CCD	Average number of fishermen at ports in CCD	Total catch (lbs) from ports in CCD	Percent of total state catch
Kekaha-Waimea	Kauai	High	2	51	142,814	0.51
Honolulu	Oahu	Medium- High	6	537	22,131,466	78.76
East Molokai	Molokai	Medium- High	11	34	40,670	0.14
Ewa	Oahu	Medium- High	8	70	73,672	0.26
Koolaupoko	Oahu	Medium- High	8	278	461,485	1.64
Hanalei	Kauai	Medium- High	3	59	42,375	0.15
Koolauloa	Oahu	Medium- High	3	19	15,871	0.06
Kihei	Maui	Medium-Low	2	210	206,302	0.73
North Kona	Hawaii	Medium-Low	3	616	1,385,911	4.93

Table 3.6 Risk of inundation and SLR index by CCD with number of ports, average number of fishermen, and average annual catch in pounds from 2009-2013.

CHAPTER 4: DISCUSSION

The overall risk from inundation that a community faces is a product of many factors, including likelihood of exposure to inundation and vulnerability of community structure. Additionally, the economic loss estimated by pounds of seafood supply landed at ports in each CCD can give an indication of the relative importance of the CCD to overall state vulnerability. The vulnerability of some CCDs has significance to the entire state due to a high proportion of the state revenue or a significant amount of catch landed at ports within their boundaries.

4.1 Overall community vulnerability

The apparently lower vulnerability of communities with businesses engaged in the marine economy contrasts with studies between coastal fishing communities and other communities on the East Coast (Colburn et al., 2016) (Figure 3.2). This may be due to the inclusion of other forms of the marine economy (as defined here) in this analysis, while previous studies focused only on fishing, in addition to the limited insights allowed by the businesses included in the ESRI (2013) database. The inclusion of multiple businesses may not give an accurate picture of the ways that the collapse of one sector may impact others and therefore the vulnerability of each CCD, particularly in the *Labor Force* estimates, could be underestimated.

High statewide CSVI scores in *Housing Disruption* and *Retiree Migration* are likely due to high housing prices and a large number of semi-permanent or vacation homes in many communities in Hawaiʻi. This puts communities in Hawaiʻi at high risk due to gentrification or rising housing prices, a risk that may increase with coastal inundation due to SLR as already-limited land on the island becomes scarcer.

All of the CCDs at risk of inundation to sea level rise exhibit low *Housing Characteristic* indicator scores. A community with low *Housing Characteristic* indicator scores may positively affect the resilience and adaptation capacity of that community. The construction of new ports in high-risk communities would likely help mitigate some of the social and economic loss by reducing the potential for catch loss.

Kekaha-Waimea CCD on Kaua‘i Island and Honolulu CCD on O‘ahu Island exhibit the highest risk scores for inundation due to SLR. Both have fairly equal CSVI scores in most categories, though Kekaha-Waimea exhibits higher vulnerability in *Labor Force* and *Housing Disruption.* Honolulu CCD does not exhibit higher social vulnerability than Kekaha-Waimea CCD in any category. This could be optimistic as it may indicate the ability to adapt to inundation and protect its citizens from economic loss as a result.

However, they both exhibit medium-high vulnerability in *Population Composition* and Kekaha-Waimea CCD exhibits high vulnerability in *Housing Disruption*, indicating a lack of resilience in the case of forced migrations. The relatively high *Population Composition* scores in both CCDSs indicate a high proportion of relatively vulnerable populations, including young children, minorities, or those that do not speak English well, which may affect some community members’ ability to relocate in the event of forced migrations.

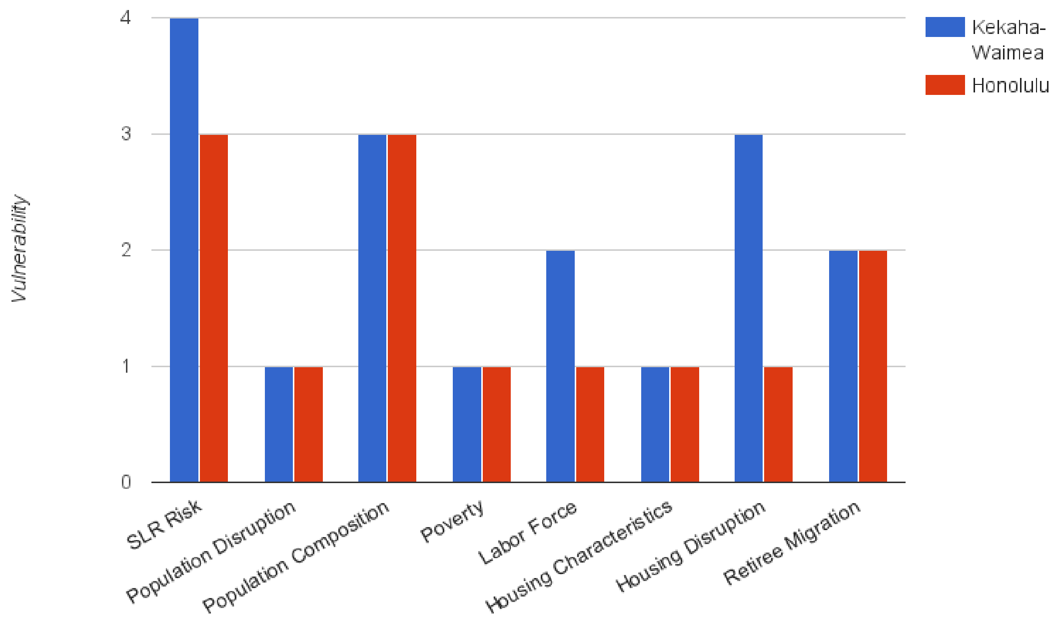

Figure 4.1 A comparison of CSVI scores between Kekaha-Waimea CCD and Honolulu CCD.

The CSVI scores of each CCD indicate that in the unlikely scenario of sea level inundation affecting only the ports or marine economy, both CCDs would likely suffer limited economic loss as their *Labor Force* and *Poverty* scores are relatively low. However, because SLR is likely to affect other infrastructure, including homes, these individuals in these communities may find it difficult to adapt in the case of forced migration due to loss of homes or transportation making certain parts of the CCD uninhabitable due to inundation.

In terms of vulnerability for individuals engaged in the marine economy, Kekaha-Waimea CCD is more concerning. On average, ports in Kekaha-Waimea CCD support a larger percentage of fishermen, with 10 fishermen per 1000 people on average from 2009-2013. Honolulu, with an average 1.4 fishermen per 1000 people, is slightly below the state average of 1.6 average fishermen per 1000 people between 2009-2013. This indicates that a larger proportion of community members in Kekaha-Waimea rely on the marine economy for their livelihoods, and these individuals, particularly fishermen, are likely to experience economic loss or income reduction in the case of sea level inundation.

Honolulu CCD does have a significant average for per capita pounds landed between 2009 and 2013, much higher than both the state average and the average in Kekaha-Waimea CCD. This could be significant for the entire state because it has implications for food security since all of the pounds landed in Honolulu CCD that account for the relatively high per capita pounds landed are likely distributed throughout the state.

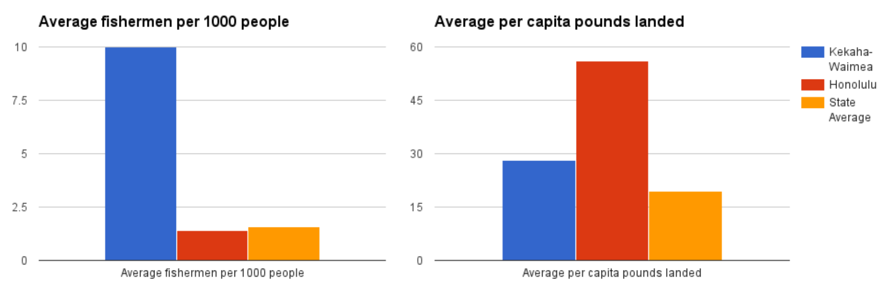

Figure 4.2 Average number of fishermen per 1000 people and average per capita pounds landed in Kekaha-Waimea CCD (blue, left-most column), Honolulu CCD (red, middle column), and the state average (yellow, right-most column).

4.2 Honolulu CCD

Most of the ports in Honolulu are located along the coast, which indicates high risk of vulnerability to SLR. This could lead to loss of infrastructure in the event of SLR inundation and lead to statewide economic loss as well as job loss or income reduction. As the most densely populated CCD in the state any loss of revenue and jobs due to SLR in Honolulu is likely to have significant statewide effects.

The low-risk indicator score for *Labor Force* characteristics in Honolulu CCD suggests that there may be work available outside the marine economy for individuals whose jobs or incomes are significantly affected by inundation due to SLR. However, fishermen are often reluctant or find it difficult to find employment in other sectors (Pollnac et al., 2014).

Fishermen have been found to be reluctant to leave the industry even when faced with increasing challenges from decreasing stock sizes or rapidly changing management, both consequences of SLR that are not considered in this project (Pollac et al., 2015). Additioanlly, even when they are willing to seek employment elsewhere, fishermenalso often have difficulty finding new work (Pollnac et al., 2015; Colburn et al., 2016). This suggests that job loss or income reduction due to SLR inundation may negatively impact fishermen in Hawai‘i, and the resulting collapse of related businesses in the marine economy could raise unemployment rates within affected CCDs and contribute to overall vulnerability.

A collapse of the fishing industry due to inundation from SLR may result in a cascading collapse of other businesses engaged in the marine economy, as well as the tourism and hospitality industries in Hawai‘i. Ports and other infrastructure that the marine economy is dependent on are vulnerable to inundation due to SLR and the high proportion of pounds landed in Honolulu CCD make this community significant to the entire state.

An estimated 35 percent of all of Hawai‘i's seafood imports from the continental U.S. are waterborne shipments, equal to an estimated 9.7 million edible pounds (Loke et al., 2016). Most of this catch is landed at ports in Honolulu CCD, which may not only affect the local seafood supply but also the imported seafood supply, with consequences for food scarcity in addition to the tourism and hospitality industries.

Despite attempts to integrate population demographics with physical SLR data, it is difficult to understand the way that community responses can or will affect the magnitude of physical consequences felt by each community (Colburn et al., 2016). Honolulu CCD is densely populated, a social characteristic that generally indicates increased vulnerability, but its high population can also represent diverse employment opportunities in the event of loss of ports or decreased catch.

4.3 Social vulnerability of communities with high SLR risk

Communities at high risk of inundation from SLR (a score of medium-high or high) generally exhibit lower CSVI scores than communities at low risk of inundation from SLR (scores of medium-low or low) (Figure 4.1). This optimistically suggests that the communities with high SLR risk may be better able to adapt to economic loss as a result of SLR inundation.

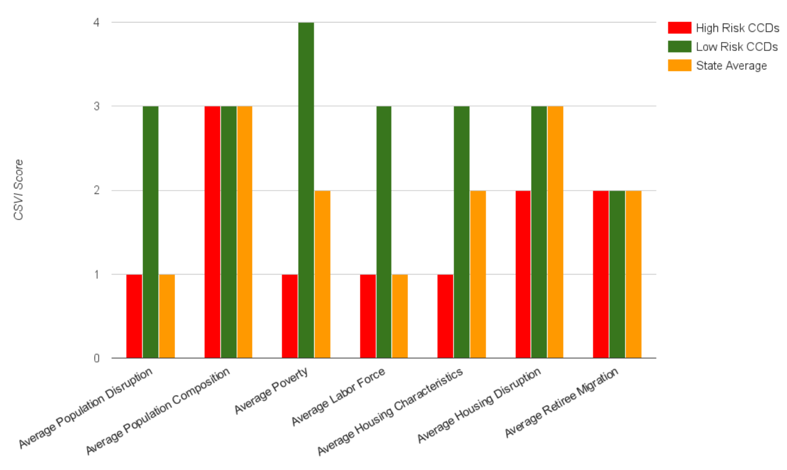

Figure 4.3 Average CSVI scores for communities with high SLR risk, low SLR risk, and state averages. A CSVI score of 1 or 2 is considered low risk, whereas scores of 3 or 4 are considered high risk.

4.4 Seafood supply lost and food security concerns due to SLR inundation

CCDs that exhibit medium-high to high risk due to SLR contain ports that where 18.5 percent of the total catch kept in the state is landed. The pounds and per capita CCD population could be used as an indicator of food scarcity, in which case communities with medium high or high risk of inundation to SLR are at higher risk for food insecurity, with over twice the pounds landed per person living in CCD (12.9 pounds per person and 26.1 pounds per person, respectively).

The per capita pounds landed could also serve as an indicator of community importance and a means of estimating the potentially localized impacts of SLR. CCDs with significantly higher per capita pounds landed could be important to the local seafood supply for the rest of the state, and if those CCDs have high SLR risk, that could be significant for the food security of the entire State of Hawai‘i.

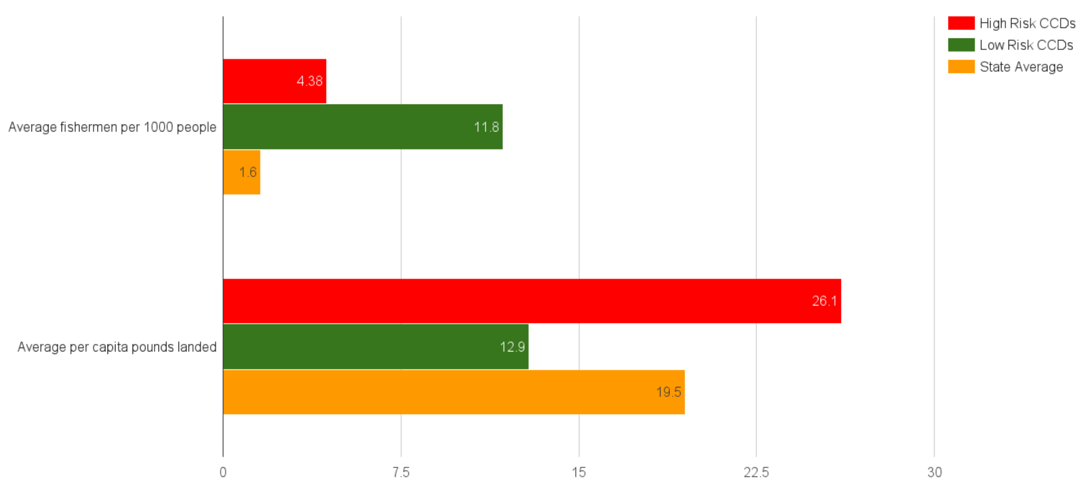

Figure 4.4 Average number of fishermen per 1000 people and average per capita catch (lbs) for high risk CCDs, low risk CCDs, and state average.

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ish and seafood markets are both lucrative sectors of the marine economy and highly connected to other marine economy industries. If other fishing or aquaculture economies are perturbed, that will likely affect the amount and quality of product available for markets and will have consequences on the state economy. While the state supports few seafood product preparation and packaging facilities, these 6 businesses account for over 25 percent of the state's revenue from the marine economy (as defined here). Though there are few seafood processing facilities in the State of Hawaiʻi, vulnerability of existing preparation and packaging businesses is connected to the vulnerability of other industries that supply fish to these businesses. They are also highly vulnerable to inundation that may affect their ports or transportation infrastructure.

4.4 Study Limitations

This analysis is limited in both its scope and because of its assumptions, though it can serve as a starting point for future studies. Not all businesses engaged in the marine economy were able to be identified using the NCAIS codes, a shortcoming made obvious by the discrepancies between reported earnings (NMFS, 2016) and the sum of revenue reported from businesses engaged in the nine sectors of the marine economy as defined here.

(1) Marine Economy. The NAICS codes used to identify businesses engaged in some sectors of the marine economy are incomplete and do not include all businesses in the state marine economy; this is apparent in the difference between total individuals employed and total revenue reported by the National Marine Fisheries Service (2016) and summed from CCD reports. The disparities may also be partially a result of inaccuracies

in catch reported in each CCD. This analysis therefore only gives a partial picture of potential economic loss in some sectors of the state economy.

Additionally, this study focuses only on local catch data as a source of seafood to the state. That does not give a complete picture of the marine economy as 57 percent of Hawai‘i’s seafood supply between 2000 and 2009 came from foreign imports (Loke et al., 2012). Therefore, the loss of local seafood supply may not be as detrimental, at least to large businesses, because some of the loss can be made up with imports.

However, the state of Hawai‘i also exports some of its seafood, with an annual average of 599,000 pounds exported between 2000 and 2009 (Loke et al., 2016). 54.8 percent of the annual pounds exported are from tuna, caught on the longline fishery (Loke et al., 2016), which lands at ports in Honolulu CCD. Honolulu CCD’s medium-high risk to inundation then becomes significant: Loss of ports and other infrastructure may affect not only local catch landings but also imports and exports.

(2) Aggregation by CCD. Because the businesses examined in this study are by no means a comprehensive picture of the state engagement in the marine economy, aggregating businesses by CCD does not give a complete picture of the distribution of revenue in the marine economy. Some industries registered in the ESRI (2013) database are likely to conduct their business in multiple industries, a complexity that is not taken into account in this analysis. Most businesses engaged in the marine economy may also rely on coastal infrastructure whether directly or indirectly, and therefore the threat of inundation may be underestimated for some businesses in this analysis.

CHAPTER 5: CONCLUSIONS

Relative vulnerability to the consequences of sea level rise within the state is affected by a community's physical risk, community demographics, and engagement in the marine economy. Identifying communities engaged in the marine economy and comparing their relative risk to inundation from SLR as well as indicators of community vulnerability can be a tool to predict the ways that a community may respond to the effects of SLR. Additionally, identifying where the revenue from the marine economy is concentrated can give clues as to which communities have the greatest effect on the state's overall marine economy, and therefore may be helpful to take into account when considering the allocation of funding.

Projected economic loss from changes due to SLR can be an indicator of community vulnerability. Communities on the western coasts of the Hawaiian Islands appear to be at higher risk of inundation due to sea level rise, and despite a higher percentage of CCDs with businesses engaged in the marine economy exhibiting low risk for many CSVI scores, the economic loss if these CCDs were to collapse could close to 20 percent of annual catch.

In the state of Hawai‘i, much of the revenue from the marine economy is highly concentrated into Honolulu CCD. Again, this could be either beneficial or harmful to the state marine economy, as the impacts of SLR on this CCD will likely be similar to the effects statewide. Honolulu's medium-high risk to SLR inundation is concerning as it represents the largest percentage of state earnings in the marine economy, which if lost or reduced could have impacts that extend beyond the CCD boundaries.

However, Honolulu CCD displays relatively low CSVI scores in almost all categories, suggesting relatively high adaption capacity, an optimistic sign considering it accounts for over half the state revenue in the marine economy. Relatively low CSVI scores suggest a community may be more resilient than others, and thus more capable of funding and implementing adaptation measures that mitigate or reduce the negative impacts associated with a physical disturbance, such as SLR.

The projected loss of catch can also estimated by identifying which CCDs are at risk from sea level rise, and determining their percentage of the state's total catch. The seven CCDs with highest risk of inundation due to sea level rise comprise 30 percent of the catch, an initially alarming figure, but each CCD that experiencing relatively high risk due to SLR also has relatively low Housing Characteristic indicator scores, suggesting communities may be resilient and able to adapt by strengthening, modifying, or replacing threatened infrastructure.

5.1 Possible Extensions

While catch landed by CCD helped predict community vulnerability due to SLR, further investigation could work to quantify the cascading effect in other sectors of the marine economy due to collapse of the fishing industry.

Tourism is estimated to be roughly a third of the state's economy and therefore loss of profit due to tourism may also significantly increase community vulnerability. A valuable extension may be to investigate the possible economic impacts on the tourism industry that communities may experience due to inundation.

This analysis provided only limited insights into the marine economy; a more thorough analysis of businesses engaged in the marine economy at the CCD level could be valuable and provide more information about the relative concentration of revenue.

Additionally, an analysis of historical trends could provide insight into the ways that communities engaged in the marine economy have responded to disturbances in the past, which may give indication of their adaption capabilities in the future. The ways that a community has responded in the past could help predict their ability to respond in the future.

Furthermore, SLR is expected to contribute to changes in species range and availability in addition to the loss of infrastructure from inundation predicted by this study (Colburn et al, 2016). This could be done in part by examining the historical catch data to see how communities have responded to changes in species availability in the past.

APPENDIX A

Businesses Engaged in the Limited Marine Economy by CCD

Industry	CCDs involved	Number of Businesses	Island	Number Employed	Revenue
FISHING					
Finfish fishing					
	Hilo CCD	1	Hawai'i	2	$78,000
	North Kona CCD	1	Hawai'i	1	$47,000
	Wailuku CCD	1	Māui	2	$500,000
	Total	3		5	$625,000
Shellfish fishing	East Moloka'i CCD	1	Moloka'i	4	$190,000
	Honolulu CCD	10	O'ahu	29	$2,842,000
	Total	11		33	$3,032,000
Other marine fishing	Honolulu CCD	3	O'ahu	16	$2,510,000
	Ewa CCD	4	O'ahu	21	$1,310,000
	Waianae CCD	1	O'ahu	1	$64,000
	Koloa-Poipu CCD	1	Kaua'i	1	$59,000
	Kekaha-Waimea CCD	2	Kaua'i	2	$75,000
	Total	11		38	$4,018,000
	Industry Totals	**24**		**76**	**$7,675,000**
AQUACULTURE					
Finfish farming and fish hatcheries	Hilo CCD	2	Hawai'i	5	$160,000
	North Kona CCD	9	Hawai'i	66	$4,830,000
	Hana CCD	1	Māui	2	$110,000
	Koolaupoko CCD	4	O'ahu	11	$1,538,000
	Ewa CCD	3	O'ahu	11	$1,000,000
	Waialua CCD	1	O'ahu	3	$90,000
	Waianae CCD	1	O'ahu	1	$48,000
	Koolauloa CCD	1	O'ahu	26	$1,400,000
	Lihue CCD	1	Kaua'i	1	$43,000
	Total	23		126	$9,219,000
Shellfish farming	North Kona CCD	2	Hawai'i	17	$1,470,000
	Kekaha-Waimea CCD	2*	Kaua'i	6	$370,000
	Total	4		23	$1,840,000
Other aquaculture	North Kona CCD	1	Hawai'i	1	$49,000
	Haiku-Pauwela CCD	1	Māui	2	$72,000
	Koolaupoko CCD	2	O'ahu	4	76,500
	Honolulu CCD	3	O'ahu	23	$1,300,000
	Waialua CCD	1	O'ahu	2	$78,000
	Waianae CCD	1	O'ahu	1	$42,000
	Koolauloa CCD	1	O'ahu	5	$49,000
	Kekaha-Waimea CCD	1	Kaua'i	8	$1,500,000
	Kaumakani-Hanapepe CCD	1	Kaua'i	0	$750,000
	Total	12		46	$3,916,500

	Industry Totals	**39**		**195**	**$14,975,500**

SEAFOOD COMMERCE

Fish and seafood markets	Paauhau-Paauilo CCD	1	Hawai'i	2	$190,000
	South Kona CCD	1	Hawai'i	2	360,000
	Lahaina CCD	1	Māui	3	$190,000
	Wailuku CCD	4	Māui	10	$660,000
	Kehei CCD	1	Māui	5	$350,000
	Makawao-Paia CCD	1	Māui	3	$310,000
	Koolaupoko CCD	1	O'ahu	4	$480,000
	Honolulu CCD	21	O'ahu	64	$13,786,666
	Wahiawa CCD	1	O'ahu	3	$220,000
	Waialua CCD	1	O'ahu	4	$480,000
	Waianae CCD	1	O'ahu	3	$284,000
	Kaumakani-Hanapepe CCD	1	Kaua'i	3	$220,000
	Koloa-Poipu CCD	1	Kaua'i	4	$320,000
	Hanalei CCD	1	Kaua'i	3	$210,000
	Lihue CCD	1	Kaua'i	6	$400,000
	Kapaa CCD	2	Kaua'i	2	$120,000
	Total	40		121	$18,580,666
Seafood product preparation and packaging	Hilo CCD	2	Hawai'i	9	$805,000
	Honolulu CCD	3	O'ahu	53	$12,840,909
	Eleele-Kalaheo CCD	1	Kaua'i	4	$240,000
	Total	6		65	$13,885,909
	Industry Totals	**46**		**186**	**$32,466,575**
	STATE TOTALS	109		457	$55,117,075

APPENDIX B

Variables Used to Generate CSVI Indices (from Jepson and Colburn, 2013).

Index Variable
1. Personal Disruption
Percent unemployed
Crime index
Percent with no diploma
Percent in poverty
Percent females separated
2. Population Composition
Percent white alone
Percent female single headed households
Percent population age 0-5
Percent that speak English less than very well
3. Poverty
Percent receiving assistance
Percent of families below poverty level
Percent over 65 in poverty
Percent under 18 in poverty
4. Labor Force
Percent females employed
Percent population in the labor force
Percent of class of worked self employed
Percent population receiving social security
5. Housing Characteristics
Median rent (in dollars)
Median mortgage (in dollars)
Median number of rooms
Percent mobile homes
6. Housing Disruption
Percent change in mortgage
Percent change in home values
Percent of owners with monthly costs greater than 35% of income
7. Retiree Migration
Households with one or more over 65
Percent population receiving social security
Percent receiving retirement income
Percent in labor force

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