In cooperation with the Civil Defense Division of the State of Hawai‘i Department of Defense, the Office of Planning of the State of Hawai‘i Department of Business, Economic Development, and Tourism, and the Pacific Disaster Center

Variations in Community Exposure and Sensitivity to Tsunami Hazards in the State of Hawai‘i

Scientific Investigations Report 2007-5208

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FRONT COVER—The communities of Punalu‘u (left) and Honolulu (right) on the island of O‘ahu.

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Variations in Community Exposure and Sensitivity to Tsunami Hazards in the State of Hawai‘i

By Nathan Wood[1], Alyssia Church[2], Tim Frazier[2], and Brent Yarnal[2]

Abstract

Hawai‘i has experienced numerous destructive tsunamis and the potential for future events threatens the safety and economic well being of its coastal communities. Although tsunami-evacuation zones have been delineated, what is in these areas and how communities have chosen to develop within them has not been documented. A community-level vulnerability assessment using geographic-information-system tools was conducted to describe tsunami-prone landscapes on the Hawaiian coast and to document variations in land cover, demographics, economic assets, and critical facilities among 65 communities. Results indicate that the Hawai‘i tsunami-evacuation zone contains approximately 80,443 residents (seven percent of the total population), 67,113 employees (eleven percent of the State labor force), and 50,174 average daily visitors to hotels (44 percent of the State total). With regards to economic conditions, the tsunami-evacuation zone contains 5,779 businesses that generate $10.1 billion in annual sales volume (both eleven percent of State totals), and tax parcels with a combined total value of $36.1 billion (18 percent of the State total). Although occupancy values are not known for each facility, the tsunami-evacuation zone also contains numerous dependent-population facilities (for example, child-day-care facilities and schools), public venues (for example, religious organizations and parks) and critical facilities (for example, fire stations). The residential population in tsunami-prone areas is racially diverse, with most residents identifying themselves as White, Asian, or Native Hawaiian and Other Pacific Islander, either alone or in combination with one or more race. Fifty-three percent of the households in the tsunami-evacuation zone are renter occupied. The employee population in the tsunami-evacuation zone is largely in accommodation and food services, health services, and retail-trade sectors.

Results indicate that community vulnerability, described here by exposure (the amount of assets in tsunami-prone areas) and sensitivity (the relative percentage of assets in tsunami-prone areas) varies considerably among 65 coastal communities in Hawai‘i. Honolulu has the highest exposure, Punalu‘u has the highest sensitivity, and Nāpili-Honokōwai has the highest combination of exposure and sensitivity to tsunamis. Results also indicate that the level of community-asset exposure to tsunamis is not determined by the amount of a community’s land that is in tsunami-evacuation zones. Community sensitivity, however, is related to the percentage of a community’s land that is in the tsunami-prone areas. This report will further the dialogue on societal risk to tsunami hazards in Hawai‘i and help identify future preparedness, mitigation, response, and recovery planning needs within coastal communities and economic sectors of the State of Hawai‘i.

Introduction

The 2004 Sumatra-Andaman earthquake and tsunami devastated communities throughout the Indian Ocean and demonstrated to the world how tsunamis are significant threats to the safety, security, economic well being, and natural resources of many coastal communities. The State of Hawai‘i has also experienced many catastrophic tsunamis in the past century (Landers and Lockridge, 1989; Dudley 1999) and is likely to experience more in the future, generated either by near-field sources in the Hawaiian Islands or by far-field sources from around the Pacific Ocean.

Near-field tsunamis that affect Hawai‘i are generated when local earthquakes, submarine slides, or landslides cause a vertical displacement of the overlying or adjacent water column (Walker, 1999; Walker, 2002). Although locally devastating to nearby shorelines and striking within minutes of the initial ground disturbance, near-field events typically lack the energy to travel long horizontal distances (Lockridge, 1998). Tsunami-related geologic deposits found at more than 300 meters above sea level on Lāna‘i Island are believed to be the result of a nearby submarine slide that occurred over 100,000 years ago (Moore and Moore, 1984). A recent near-field event was the 1975 tsunami, generated by a magnitude 7.2 earthquake on the Big Island of Hawai‘i, that killed two people and caused $1 million in property damage (Landers and Lockridge, 1989; Goff and others, 2006). A review of locally generated tsunamis indicates average recurrence intervals of approximately 20 years for destructive tsunamis (Walker, 1999).

Far-field tsunamis, also referred to as teletsunamis, are created by earthquakes generated on the seismically active Pacific Ocean margin and strike Hawaiian coastlines several

[1] U.S. Geological Survey
[2] The Pennsylvania State University

hours after the earthquake (Walker, 2005a; Walker, 2005b; Tang and others, 2006). Primary sources for previous far-field tsunamis that have struck Hawai‘i include the Kuriles-Kamchatka-Aleutian region to the north and northwest and South America to the southeast (Cox and Mink, 1963). A far-field tsunami in 1960, generated by a magnitude 8.6 Chilean earthquake, had a maximum run-up height of 35 feet in Hilo, killed 61 people and caused $24 million in property damage (Eaton and others, 1961; Lachman and others, 1961; Cox and Mink, 1963; Mader and Curtis, 1991; Johnston, 2003; Atwater and others, 2005). Another significant far-field event was the 1946 tsunami, generated by a magnitude 7.3 earthquake in the Aleutian Islands, that killed 159 people and caused $26 million in property damage (Landers and Lockridge, 1989; Dudley and Stone, 2000). Recent work on far-field tsunami potential suggests that wave run-up is fairly focused and, given a detailed tsunami warning, limited evacuations of specific areas may be more appropriate than statewide evacuations (Walker, 2004).

Tsunamis, both near-field and far-field events, are constant threats to coastal communities and the potential for inundation is significant for low-lying areas along the Hawaiian coast. Occupation and use of tsunami-prone land, however, varies considerably in Hawai‘i, from small villages (fig. 1*A*) to dense residential communities (fig. 1*B*) to large cities with significant industrial and commercial sectors (fig. 1*C* and 1*D*). These variations in the geographic distribution of human settlement influence how communities are vulnerable to tsunamis. A tsunami may cause damage to individual assets and communities, but the cumulative choices a society makes with regards to land use prior to an event set the stage for these losses (Mileti 1999; Wisner and others, 2004). The combination of hazardous landscapes and vulnerable human systems create the risk for future disasters. Although much has been done to improve our understanding of tsunami hazards and to develop warning systems in the United States (for example, the Pacific Tsunami Warning System), less has been done to understand community vulnerability to these hazards, specifically the potential impacts on people and infrastructure (Walker, 2005a; U.S. Government Accountability Office, 2006).

In 2006, the State of Hawaii Department of Defense, Civil Defense Division (HSCD) contacted the U.S. Geological Survey (USGS) seeking technical assistance in assessing community vulnerability to tsunami hazards in Hawai‘i. Tsunami-evacuation zones have been developed for the State (Curtis 1991) but the HSCD was interested in knowing what community assets were in these areas and how community vulnerability to tsunamis varies across the State. The HSCD focuses on forging partnerships with Federal, State, and local agencies, volunteers, and private organizations to communicate the potential effects of coastal hazards and on developing preparedness and response procedures. Two local HSCD partners are the State of Hawai‘i Office of Planning (OP) and the Pacific Disaster Center (PDC). Two functions relevant to this project that the OP administers are the State-

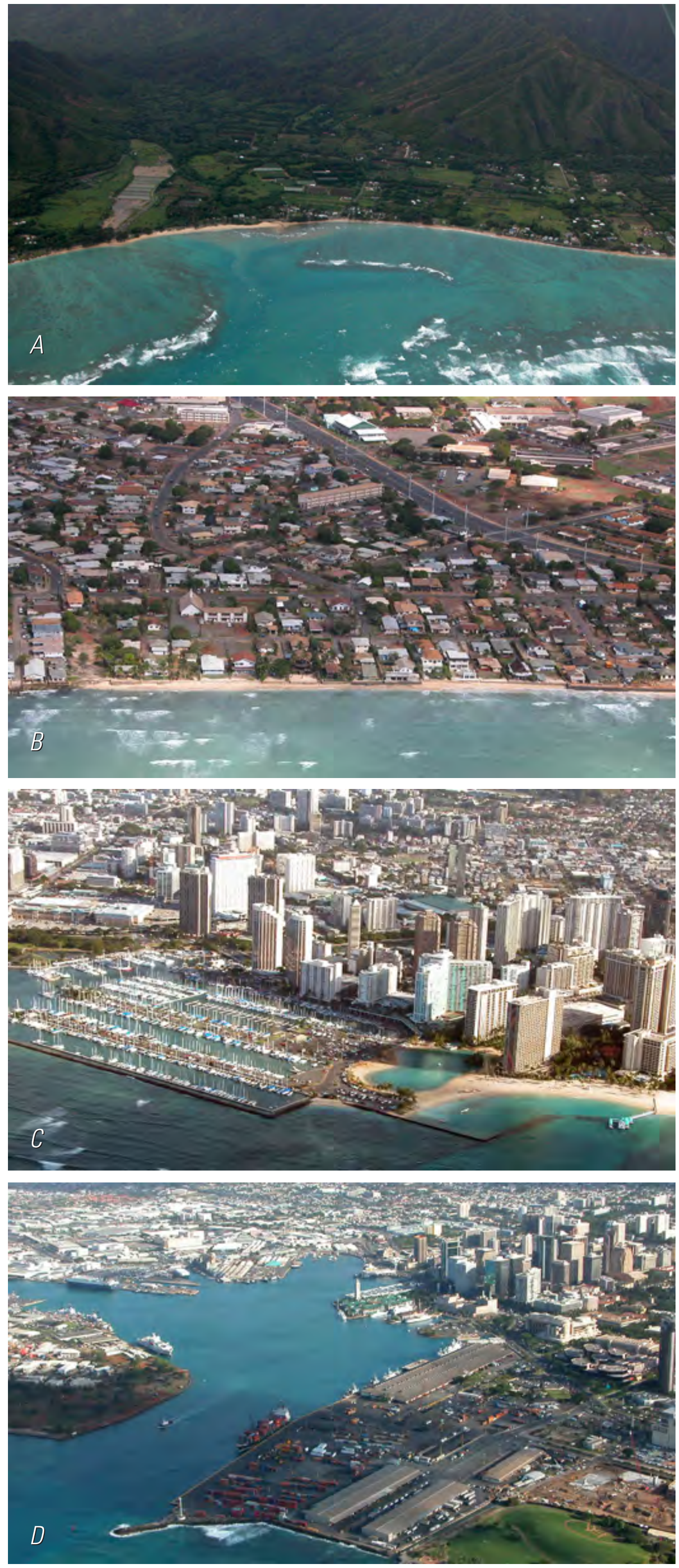

Figure 1. Oblique photographs of (*A*) the community of Punalu‘u (*B*) the community of Ewa Beach, (*C*) the Ala Wai Boat Harbor near Waikīkī Beach, Honolulu, and (*D*) Honolulu Harbor.

wide Geographic Information System (GIS) Program and the Hawai‘i Coastal Zone Management Program, which seeks to educate the public on coastal hazards. The PDC provides applied-research support to the disaster-management and humanitarian-assistance communities of the Asia-Pacific region and beyond. To complement current efforts to educate communities about tsunamis in Hawai‘i, the HSCD, OP, PDC and USGS developed a formal partnership in 2006 to better understand and communicate societal vulnerability to tsunamis in Hawai‘i.

Community vulnerability, defined here as the attributes of a human-environmental system that increase the potential for hazard-related losses or reduced performance, is primarily determined by how communities occupy and use hazard-prone land. Vulnerability is characterized by the exposure, sensitivity, and resilience of a community and its assets in relation to stressors, either chronic or sudden (Turner and others 2003). Vulnerability has been described as hidden weaknesses that are uncovered when a system experiences an extreme physical event (Bogardi, 2004). Vulnerability assessments focus on identifying system weaknesses and why they may exist (for example, social, political or economic forces). Vulnerability assessments are also required elements of natural-hazard mitigation plans that must be prepared and adopted by local and State governments to qualify for project grant funds under the U.S. Hazard Mitigation Grant Program, as mandated by the Disaster Mitigation Act of 2000 (DMA 2000), Public Law 106-390.

Understanding community vulnerability to a hazard is critical if public officials and private citizens are to mitigate risk and prepare before an event, as well as respond and recover effectively after an event. Understanding how community vulnerability varies to a regional hazard (for example, tsunamis) allows local and State decisionmakers to prioritize limited mitigation and emergency-planning resources, as well as provides context for response exercises. In some cases, vulnerability assessments can help determine the need for site-specific hazard assessments (Curtis, 1999) or risk assessments, which differ from a vulnerability assessment by focusing on determining the joint probability of an event occurring and the subsequent damage or loss of a specific asset. In other cases, vulnerability assessments are the preferred products if risk assessments are unattainable (due to the inability to precisely measure physical events or asset fragility) or are not needed (for example, if the intended risk-management strategies are evacuation plans and awareness programs) (Weichselgartner, 2001).

Purpose and Scope

The purpose of this report is to describe tsunami-prone landscapes on the Hawaiian coast and to document geographic variations in community vulnerability to tsunamis. Data presented in this report include descriptions of land cover, human population, economic assets, and critical facilities relative to tsunami-evacuation zones. For the purposes of this study, the vulnerability analysis is limited to the exposure and sensitivity of assets to tsunami hazards at the community level, summarized by tsunami-evacuation zones and by specific community. This study does not address natural resources, individual- and household-level issues, social capital and networks (Alwang and others, 2001; Pelling, 2002) or community resilience, a third component of vulnerability and defined here as the ability to withstand, absorb, adapt to, and recover from losses (Turner and others, 2003). It also does not seek to identify the underlying determinants of the variations in community vulnerability (Wisner and others, 2004).

To understand tsunami risk, policymakers, emergency managers, and private citizens must understand the potential for extreme events and the vulnerability of communities that occupy tsunami-prone land. This report provides an initial estimate of community exposure and sensitivity to tsunamis in Hawai‘i and results of this community-level analysis are intended to serve as a foundation for additional risk-related studies and outreach efforts. Knowledge on regional vulnerability issues generated by this project will help identify and tailor future preparedness, mitigation, response, and recovery planning efforts within specific communities and economic sectors in the State of Hawai‘i.

Methods and Data

To describe tsunami-prone landscapes and community vulnerability to tsunamis on the Hawaiian coast, we used geographic-information-system (GIS) tools and publicly-available geospatial data to create spatial overlays of hazard and socioeconomic data. Details on each of the socioeconomic datasets used in this analysis follow an overview of our analytical approach and the study area.

Vulnerability calculations and comparisons are limited to the exposure and sensitivity of the urban footprint and certain assets, including developed land, populations (residential, employee, and tourists), economic assets and critical facilities. Selected socioeconomic assets were chosen because U.S. jurisdictions are encouraged to collect similar data when they inventory community assets in the development of State and local mitigation plans (Federal Emergency Management Agency, 2001). Exposure is defined as the amount of an asset (for example, the number of residents of a town) within a tsunami-evacuation zone. Sensitivity is defined as the relative impact of losses to an entire community (for example, the percentage of a community’s workforce in a tsunami zone) and is calculated by dividing the amount of an asset in a tsunami-evacuation zone by the total amount of that asset in the community. For example, if community A has 100 businesses in a tsunami-evacuation zone (representing 10 percent of the local economy) and community B has 30 businesses in a tsunami-evacuation zone (representing 90 percent of the local community), then community A has a higher economic exposure because it has more businesses in the tsunami zone, but community B is more economically sensitive because it has a higher proportion of its businesses in the tsunami zone. Exposure and sensitivity values of various socioeconomic characteristics are calculated and reported for each community. Certain values are then normalized and combined to create overall indices of community exposure and sensitivity to tsunami hazards in Hawai‘i. Finally, we perform statistical analyses to determine if the distribution of community assets depends on the amount of land in tsunami-evacuation zones.

Before calculating exposure and sensitivity values, all geospatial data were processed to share the same datum (North American Datum of 1983) and projection (Universal Transverse Mercator coordinate system zone 4N). This particular datum and coordinate system were chosen to conform to existing GIS data from the State of Hawai‘i's GIS database. Spatial analysis of vector data (for example, business points and tax-parcel polygons) focused on determining if points or polygons were inside the tsunami-evacuation-zone polygons. Slivers of polygons that overlap administrative boundaries and tsunami zones are taken into account during analysis and final values were adjusted proportionately. Spatial analysis of raster-grid data (for example, land-cover data) was conducted in a raster environment to maintain data quality.

Because of the short project timeline established by project partners, no new datasets were generated and no fieldwork was conducted to verify the accuracy of any geospatial data discussed in this report. Therefore, we cannot guarantee initial data accuracy; results should be considered first approximations and developed solely for the purposes of generating discussions for additional, more-detailed studies.

Study Area

This study focuses on all land within the State of Hawai‘i, including the counties of Hawai‘i, Honolulu, Kaua‘i, and Maui. The State of Hawai‘i does not have incorporated cities; therefore, census-designated place (CDP) boundaries from the U.S. Census Bureau were used to delineate communities (Hawai‘i Office of Planning, 2007; U.S. Census Bureau, 2007a). A census-designated place is a delineation used by the U.S Census Bureau to identify areas of settled concentrations of populations that are identifiable by name and are often defined in cooperation with local or tribal officials but are not legally incorporated and lack separate municipal governments (U.S. Census Bureau, 2007a).

Tsunami-prone land is spatially delineated by a series of tsunami-evacuation polygons developed in 1991 for the State (Hawaii Office of Planning, 2007). The tsunami-evacuation zones available for the entire State are based on historical evidence and one-dimensional models of topography that do not take into account the effects of sea-floor changes (Curtis, 1991). The development of new tsunami-inundation maps using historic data from past tsunami events and two-dimensional numerical models that incorporate bathymetric variations is currently underway. To date, updated tsunami-inundation models and maps are limited to the island of O‘ahu (Wei, 2004) and completion of the entire State's coastline will take several years. Due to the State-level perspective and timeliness of this assessment, tsunami-evacuation zones developed in 1991 are used in the GIS analysis. However, analysis can be updated based on methods outlined in this report as new information on tsunami-inundation potential becomes available in the coming years.

Based on a spatial overlay of CDP and tsunami-evacuation-zone data, there are 65 CDPs (hereafter called communities) in the State of Hawai‘i that contain tsunami-prone land (fig. 2). Note that figure 2 does not show all CDP boundaries in the State of Hawai‘i, only those that overlap with the tsunami-evacuation zones. Ni‘ihau Island is not shown in the Kaua‘i County portion of the map because it contains no CDP boundaries; any assets on this island are reflected in Kaua‘i County totals. Community assets in the area formerly known as Kalawao County, now considered a Maui County judicial district, are reported in the non-CDP portion of Maui County. Further spatial analysis to characterize land in tsunami-evacuation zones and to assess socioeconomic variations focuses on 69 geographic units, which includes the 65 communities and the non-CDP portions of the four counties. Official names and spellings of geographic features and communities throughout the report follow recommendations of the Hawai‘i Board on Geographic Names (2007).

Land-Cover Data

A first step in understanding the potential loss from tsunamis is to determine what kind of land use and land cover (LULC) are in predicted hazard zones, with specific attention given to patterns of human development. To characterize land cover in tsunami-prone areas, we use 2000-2001 land-cover data compiled by the National Oceanic and Atmospheric Administration's (NOAA) Coastal Change Analysis Program (C-CAP), a nationally standardized land-cover database for the coastal regions of the United States (NOAA CSC 2007; Dobson and others, 1995) and part of the National Land Cover Database (NLCD) effort through the interagency Multi-Resolution Land Characteristics (MRLC) Consortium (Homer and others, 2004; Loveland and Shaw, 1996). NLCD products, including LULC, percent impervious cover, and percent canopy cover, are automatically derived from Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM) digital satellite imagery, which is produced at a 30-meter spatial resolution. C-CAP data has a reported accuracy standard of 85 percent (Dobson and others, 1995).

NOAA C-CAP data generated before 2005 has 22 land-cover classes, with human development primarily represented by low-intensity developed and high-intensity developed classes. Low-intensity developed cells contain 25 to 75 percent of impervious surfaces, are a mix of constructed and vegetated surfaces, and typically represent small buildings, streets, and cemeteries. High-intensity developed cells contain more than 75 percent impervious surfaces, have little or no vegeta-

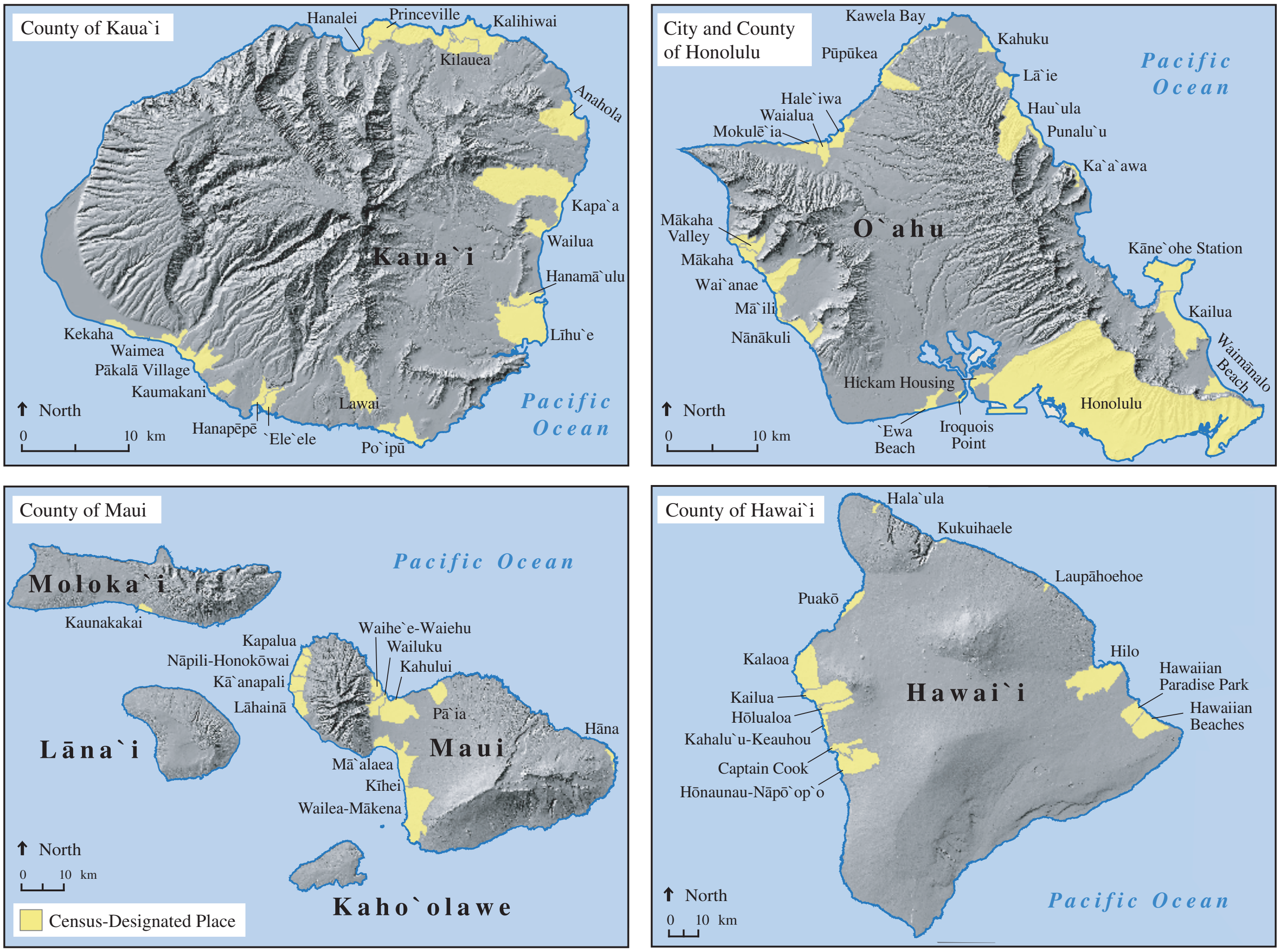

Figure 2. Map of the State of Hawai‘i, including census-designated places that intersect tsunami-evacuation zones.

tion, and typically represent heavily built-up urban centers, large buildings, and large paved surfaces, such as runways and interstate highways (Dobson and others, 1995). Figure 3 shows 2000 land-cover data for the island of O‘ahu, in which the high concentration of high- and low-intensity developed land-cover cells in the southeastern corner denote the highly-developed areas of Honolulu.

As one indicator of community exposure and sensitivity to tsunami hazards, we calculate the amount and percentage of developed land, defined here as land-cover cells classified as either low- or high-intensity developed, in relation to tsunami-evacuation zones and to CDP boundaries. This information does not translate to loss potential of any specific asset within a cell, as land classified as developed could be, for example, interstate highways, parks, residential homes, or commercial parks. However, comparing landscape compositions at the regional scale does provide some insight into the relationship between developed areas and predicted hazards within communities and we assume that community vulnerability increases with greater amounts and percentages of cells classified as developed in tsunami-prone areas.

Population Data

The high number of casualties associated with 2004 Sumatran-Andaman event demonstrated how tsunamis are significant threats to human safety in coastal communities. All individuals occupying tsunami-prone land have the potential to be injured or killed, but demographic factors like age, race, gender, and socioeconomic status can amplify the potential for losses and create varying recovery times (Morrow, 1999; Cutter and others, 2003; Laska and Morrow, 2007). In addition, risk-reduction, response, and recovery strategies will differ for each community depending on their relative number of residents, employees, dependents, and tourists that may be at risk from tsunamis.

To determine the number and type of residents in the tsunami-evacuation zones, we use block-level population counts and demographic data from the 2000 U.S. Census (U.S. Bureau of Census, 2001). Additional demographic attributes are available for larger census areas (for example, block groups and census tracts); however, we believe it is inappropriate to use data at these scales because of the significant size

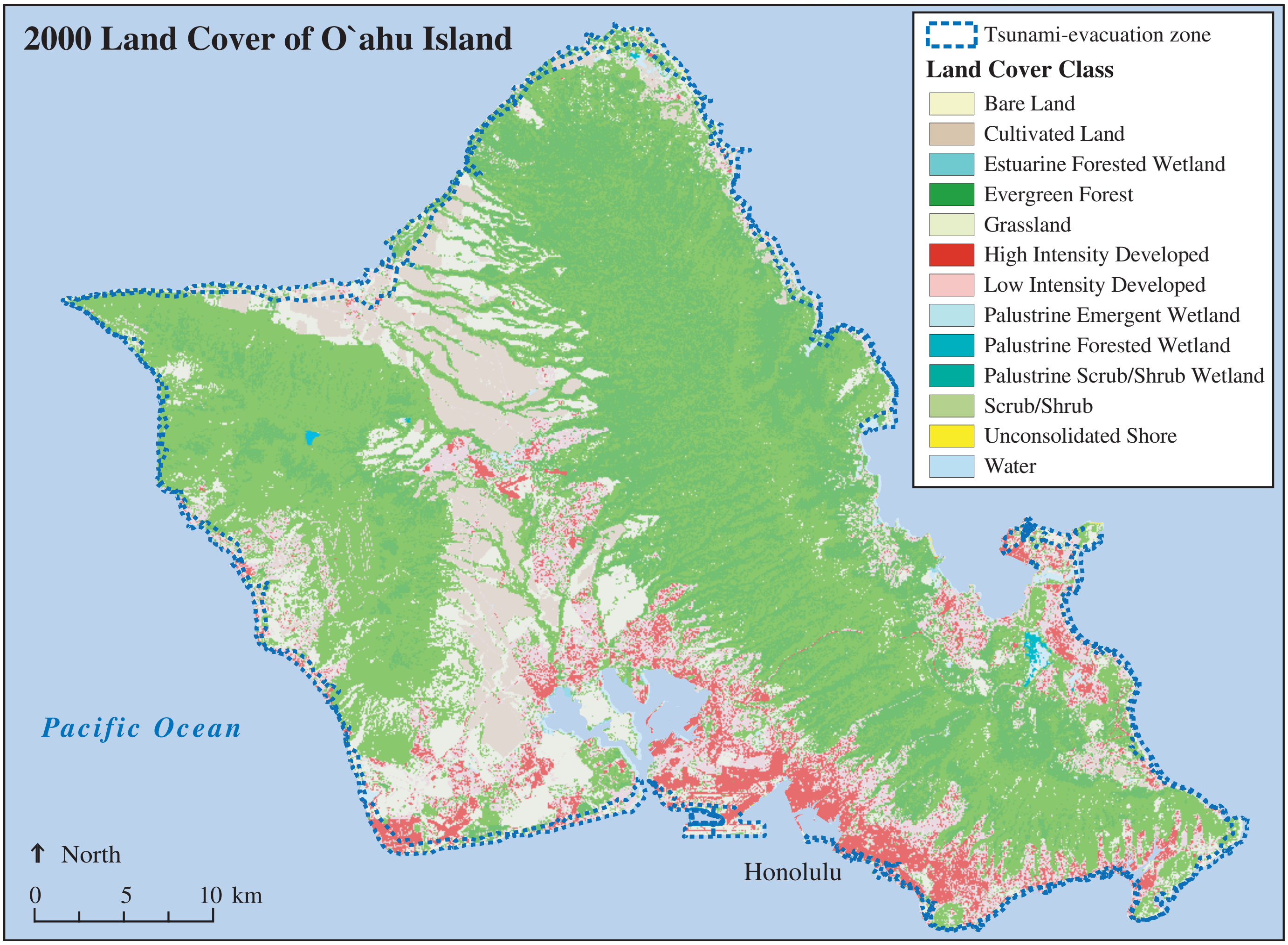

Figure 3. Map of land-cover type for the Island of O‘ahu.

differences between evacuation polygons and larger block-groups. Results presented later in the report portray the sum of population or demographic values and not the total number of blocks for the following residential-population characteristics of Census block-level data:

- Total population
- Hispanic or Latino population
- White alone or in combination with one or more other races
- Black or African American alone or in combination with one or more other races
- American Indian and Alaska Native alone or in combination with one or more other races
- Asian alone or in combination with one or more other races
- Native Hawaiian and other Pacific Islander alone or in combination with one or more other races
- Median age
- Population less than 5 years in age
- Population more than 65 years in age
- Female population
- Households
- Renter-occupied houses
- Female-headed households, with children

Other local at-risk populations are employees. For coastal states like Hawai‘i, most businesses are near the shore; therefore, many individuals occupy tsunami-prone land for their jobs, representing a significant evacuation issue for emergency managers. Employee analysis is based on the 2006 infoUSA Employer Database, a proprietary database comprised of georeferenced point files representing businesses, each with attributes of employees, sales volume and North American Industry Classification System (NAICS) codes. Analysis is based on a point’s presence within a tsunami-evacuation zone. Employee results presented here are the sum of employees and not the number of business. Additional business-related analysis is provided in the economic portion of the report.

In addition to residents and employees, a third category of local at-risk individuals are dependent populations, defined here as individuals who temporarily reside in facilities where they would be dependent on external assistance to evacuate and recover. Facilities with such populations include adult residential care, child day care, correctional facilities, hospitals, outpatient-care centers, psychiatric and substance-abuse hospitals, and schools. We used the infoUSA Employer Database and specific NAICS codes (appendix A) to identify the location of these dependent populations. We summarize the total number of facilities and not the number of individuals in each facility, which was beyond the scope of this limited study.

Tourists represent the fourth significant population component in coastal communities, a segment that can often outnumber residents and employees in hazard-prone areas (Wood and Good, 2004). To develop realistic preparedness and response strategies, emergency managers need to know where large numbers of tourists are; however, unlike resident and employee populations, there is no consistent census of tourist numbers. To gauge the whereabouts of tourists in this study, we simply identify two areas where tourists are likely to congregate—public venues and hotels.

Identifying public venues provides some insight on where significant numbers of tourists and local residents may congregate during the day and where significant evacuation issues may exist if a tsunami occurs. Although we cannot determine how many people visit these sites at a given time, knowing where public venues are provides emergency managers with some insight on community vulnerability hotspots. Using NAICS codes in the 2006 infoUSA Employer Database (appendix A), we focus on the following public-venue facilities:

- Aquariums
- Botanical gardens
- Colleges, universities, trade schools and other educational facilities
- Historical places
- Libraries
- Museums
- Parks
- Religious organizations
- Shopping centers and malls
- Sporting facilities
- Theaters
- Zoos

In addition to the “historic places” code in the infoUSA Employer Database, we also use information from the National Park Service’s National Registry of Historic Places (National Park Service, 2007) to determine how many historic places are in tsunami-evacuation zones. Historic-place data are point files, so spatial analysis is based on whether a point is in or out of an evacuation zone. Due to the relatively low number of sites, point locations were verified and revised using address information gathered from the Internet.

To gauge the number of overnight tourists that may be at risk from tsunamis, we used hotel data provided by the Office of Planning that included georeferenced business points, each with an average-daily-visitors (ADV) estimate. The database includes all moderate to large hotels, but not smaller hotels, bed and breakfast facilities, or campgrounds. Therefore, results should be considered as estimates and not exhaustive statements of tourist populations.

Economic Data

Tsunamis, like most extreme natural events, pose significant threats to the economy of coastal communities. For this study, we focus on two elements of the Hawaiian economy—tax base and the business community. Tax base is represented by current parcel values and is considered an attribute of community vulnerability because communities rely on property taxes for local services. Although communities can typically expect disaster-relief aid from State and Federal sources, as well as from non-profit organizations and private donations, funds for longer-term recovery typically come from the local tax base. If an extreme natural event destroys property, parcel values will decrease and the tax base of a community subsequently shrinks. If a community’s tax base drops dramatically due to disaster-related damage, then a community may have a harder time with disaster recovery. Tax-parcel analysis is based on the 2006 tax parcel dataset for the State of Hawaiʻi (Hawaiʻi Office of Planning, 2007), and parcel-polygon attributes include property value, content value, exemptions to property values and exemptions for content value (all in 2006 U.S. dollars).

Variations in the potential impact of a tsunami on the business community are gauged by looking at the distribution of businesses, employees and sales volumes generated by these businesses, as reported by the infoUSA Employer Database. In addition to summaries of businesses, employees, and sales volume for each community, the distribution of these attributes by business type was calculated for the State. Comments on regional and local labor-market conditions, such as the dominance of specific sectors in the tsunami-evacuation zone and for the entire State, are based on the number and distribution of employees, an indicator routinely used by the private and public sector to evaluate economic health and market trends (Marshall, 1989, Bureau of Labor Statistics, 2007a).

Critical-Facilities Data

Certain facilities are important for short-term response and long-term recovery of a community following a tsunami and are identified by the 8-digit NAICS code attached to each business in the infoUSA database (appendix A). For the purposes of this study, critical facilities are those considered important for short-term response operations and essential facilities are those considered important for long-term recovery. This list is not meant to be exhaustive of all facilities that will be important immediately after a tsunami strikes or during reconstruction efforts, merely beginning estimates of certain facilities for further discussions within the State of Hawai‘i. The facilities identified for this study include:

Critical facilities

- Civil-defense facilities
- Fire stations
- National-security facilities
- Police stations
- Ambulance services
- Hospitals
- Outpatient-care centers
- Offices of physicians
- Electric facilities
- Public-works facilities
- Gas facilities
- Radio and television facilities
- Waste-water facilities
- Water and sewer facilities

Essential facilities

- Banks and credit unions
- Courts and legal offices
- Gas stations
- Government offices
- International-affairs offices
- Grocery stores

Composite Indices of Exposure and Sensitivity

Emergency managers, especially those with State or Federal agencies, assess community vulnerability often in relative terms to prioritize limited resources. To facilitate comparisons for the communities presented in this report, we developed composite indices of community exposure and sensitivity to tsunami hazards in Hawai‘i. These indices of exposure and of sensitivity are based on the amounts and percentages, respectively, of developed lands, residents, employees, hotel ADV estimates, and total tax parcel values (minus exemptions) in each of the 65 communities and in the non-CDP areas of the 4 counties. Information on facilities was excluded from this analysis because the actual number of individuals at each site was not gathered.

Composite indices of exposure and sensitivity were developed for each of the 69 geographic units by first normalizing values in each category (developed land-cover cells, residents, employees, hotel ADV estimates, and parcel values) to the maximum value found within that category. For example, normalized values are $Amount_{normalized} = Amount_{original} / Amount_{maximum}$ for exposure values and $Percentage_{normalized} = Percentage_{original} / Percentage_{maximum}$ for sensitivity values. Normalizing data to maximum values creates a common data range of zero to one for all five categories and is a simple approach for enabling comparisons among disparate datasets. The five normalized values are then added together, resulting in one final score with a data range of 0 to 5 for each of the 69 geographic units. This is done for both exposure and sensitivity values. These composite scores are a relative score to compare the overall exposure and sensitivity for each of the 69 geographic units and have no stand-alone meaning for an individual community. A final score that integrates the two composite scores (exposure and sensitivity) is determined for each of the 69 geographic units by first normalizing each of the composite scores to maximum values (4.13 for composite exposure and 4.63 for composite sensitivity), creating common data ranges of zero to one for each of the indices and minimizing any weighting bias between the indices. These normalized composite indices are then simply added with no additional weighting, resulting in a final score with a potential range from zero to two.

Statistical Methods

The purpose of this study is to describe tsunami-prone landscapes on the Hawaiian coast and to document variations in community exposure and sensitivity to tsunamis. Nonparametric descriptive statistics, including medians and quartiles, are used to summarize variations among communities instead of means and standard deviations because several datasets were found not to follow a normal distribution, based on D’Agostino normality tests at $\alpha = 0.05$ (Zar, 1984).

One hypothesis that arises in the process of documenting these variations is that community exposure is directly related to the amount of land in the tsunami-evacuation zone; that is, more community land in the tsunami zone means greater exposure of community assets. To test this hypothesis, we conducted a series of simple linear regression analyses between land-area data and the various community assets, including developed lands (lands classified as either low- or high-intensity developed), residents, employees, parcel values (total value minus exemptions), and hotel ADVs. Simple linear regressions were conducted for exposure values (the amounts of community land and amounts of various community assets in tsunami-evacuation zones) and for sensitivity values (the percentages of community land and percentages of various community assets in tsunami-evacuation zones). The goal was to see if the distribution of community assets depends on the amount of land (by area) in tsunami-evacuation zones. We did not assume that the amount and percentage of community land in tsunami-prone areas are the only factors that determine asset distributions, but we did want to test whether they are significant determining factors. The independent variable was the amount or percentage of land, regardless of land-cover class, within a community. The dependent variables were the various community assets. In all cases, we were only concerned with testing the null hypothesis that no statistically significant relationship exists and not with determining the x-intercept (α) or slope (β) of the regression line. Statistical significance of a regression relationship is tested using an analysis of variances, where significance is assumed if calculated Fisher (*F*) values comparing the mean squares of the linear regression and residuals are greater than 3.98, which represents the critical *F*-value for a one-tailed test at $\alpha = 0.5$ and 67 degrees of freedom (Zar, 1984). Tests are done with an assumption of normality in the distribution of residuals (or homoscedasticity), based on a graphical examination of residual plots (Zar, 1984).

For both the exposure and sensitivity tests, we calculate the Pearson product-moment-correlation coefficient (r), the square of the Pearson product-moment correlation (r^2), the Fisher value (F), and the corresponding P-value. A P-value of less than 0.05 denotes a significant statistical relationship between land area and the specific community asset. A P-value of greater than 0.05 suggests that differences in the variances of the populations being compared (for example, land-area and number of residents) are too large to propose that a relationship exists.

Results

Results of the GIS-based analysis are summarized by tsunami-evacuation zone and by CDP-based community. An accompanying database provides data on individual communities and evacuation-zone maps (appendix B). Because of the vast amounts of data used in this analysis, this report focuses on overviews of the geospatial data, regional trends and graphics. The report is organized around four community characteristics: (1) land cover, (2) population, (3) economic assets, and (4) critical and essential facilities. In each section, third quartile values are noted on bar-graphs so that readers can quickly identify those communities that are above the 75th percentile in a given category. Quartiles are also used to organize map-based summaries of selected exposure and sensitivity results (appendix C), which are provided to help visualize spatial variations in community vulnerability. After reviewing the results of each socioeconomic category, we provide composite indices of exposure and sensitivity.

Land Cover

Based on the spatial overlay of 2000–2001 C-CAP data with CDP boundaries and the tsunami-evacuation zones, the distribution of land-cover types (by area) in tsunami-prone land was determined for the entire Hawaiian coast (fig. 4). Percentages represent the amount of land area classified as a specific land-cover class (for example, grassland) relative to the total hazard-prone area. For the purposes of this report, all wetland-related C-CAP categories are aggregated into one class. Results indicate that the dominant land-cover classes in the tsunami-evacuation zone are bare land (20 percent), scrub/shrub (20 percent), grassland (16 percent) and forest (16 percent). Twelve percent of the land is classified as low-intensity developed and five percent is high-intensity developed. A combined value of 17 percent for developed land may seem low but is fairly high, considering that the percentage of developed land in the northern Piedmont ecoregion (which includes the western portions of New York City, Philadelphia, Baltimore, and the District of Columbia and is considered one of the most developed areas in the Nation) was only 27 percent in 2000 (Auch, 2005).

Although most tsunami-prone land is not classified as low- or high-intensity developed, these areas may attract recreationists and transient populations, such as tourists, who can dominate the daily population of many coastal communities (Wood and others, 2002; Wood and Good, 2004). In addition, these undeveloped areas may represent significant natural resources or ecosystem services (for example, water-quality improvement) and their damage or loss due to a tsunami could negatively impact nearby communities or the region.

Results indicate that the amount (fig. 5*A*) and percentage (fig. 5*B*) of developed land (cells classified as either high- or low-intensity developed) varies significantly across the State of Hawai‘i. The median and third quartile (75th percentile) for the amount of developed land in CDP and non-CDP land is 0.40 km^2 and 0.82 km^2, respectively, suggesting most communities have small amounts of developed land in tsunami-evacuation zones. However, certain communities, such as Honolulu, Hilo, and Kahului (fig. 5*A*), are well above the third quartile. The greatest amounts of developed land in tsunami-evacuation zones overall are in non-CDP portions of the County of Maui and the City and County of Honolulu.

Although only a few communities have high amounts of developed land in tsunami-evacuation zones, many have a large percentage of their urban footprint in those zones (fig. 5*B*). For example, communities like Hanalei and Hale‘iwa have low amounts of developed land in tsunami-evacuation zones (0.4 and 1.2 km^2, respectively), but these lands represent close to 100 percent of their communities. Conversely, some communities have relatively high amounts of developed land

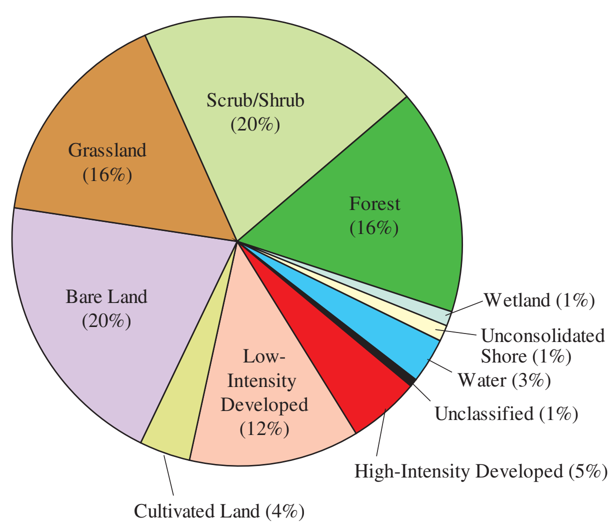

Figure 4. Distribution of land-cover classes (by area) in tsunami-evacuation zones for the State of Hawai‘i.

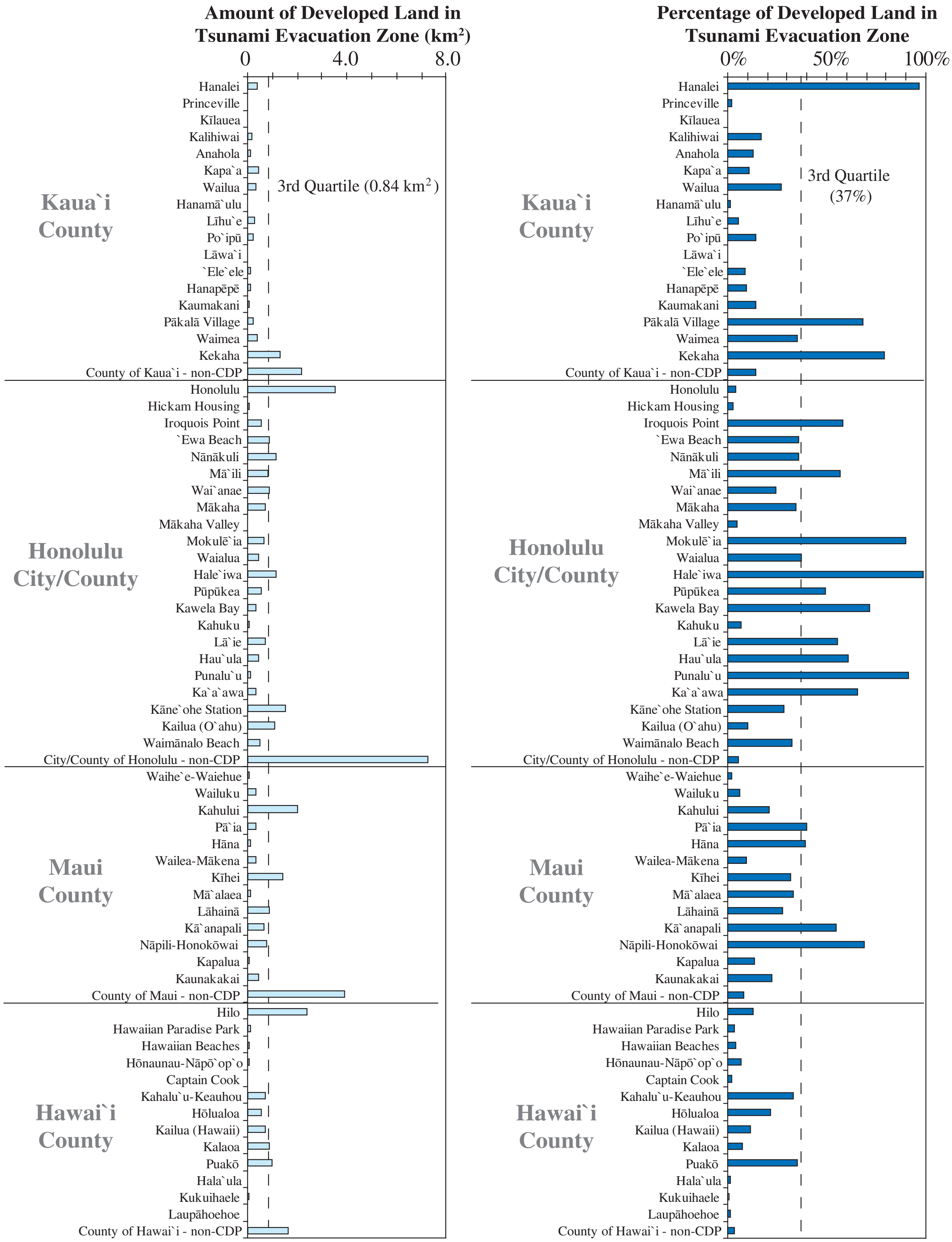

Figure 5. Amount and percentage of land-cover cells classifed as developed in tsunami-evacuation zones, organized by census-designated place.

(such as Honolulu, Hilo, and Kahului) in the tsunami-evacuation zones, but this developed land represents a small percentage of total land in these communities. Thus, in regards to development patterns, results indicate that certain communities have high exposure to tsunami hazards, but other communities have high sensitivity to the same threats.

Population

Residential Populations

Results indicate that tsunami-evacuation zones contain approximately 80,443 residents and 26,854 households (table 1), both representing 7 percent of State-level totals. The total number (fig. 6*A*) and CDP percentage (fig. 6*B*) of residents in tsunami-evacuation zones varies significantly across the State of Hawai‘i. The median and third quartile (75th percentile) for the CDP and non-CDP land is 654 and 1,795 residents, respectively. Similar to land-cover results, certain communities have high numbers of residents in tsunami-evacuation zones (for example, Hilo and Honolulu), whereas others have high percentages of their residents living in tsunami-evacuation zone (for example, Hanalei and Hale‘iwa). Results indicate that ‘Ewa Beach has the highest number of residents (5,576) in the tsunami-evacuation zone, while Hale‘iwa has the highest percentage (99 percent) of their residents in the tsunami-evacuation zone.

Studies have shown that certain demographic groups can have unique needs during an evacuation and in post-disaster recovery (Morrow 1999; Ngo 2003; Laska and Morrow, 2007). We focus here on State-level aspects of age, gender, tenancy, and race for residential populations; demographic variations among communities and counties can be found in the accompanying database (appendix B). Comments on demographic sensitivity of the residential population are based on trends observed by social scientists in past disasters throughout the world and are not meant to imply that all individuals of a certain demographic category will exhibit identical behavior in the event of a disaster. In addition, variations in local cultures and individual or community resilience, aspects not covered in this report, will influence the extent of these unique needs.

One demographic characteristic that influences an individual’s sensitivity is age (Morrow, 1999; Ngo, 2001; Balaban, 2006; Laska and Morrow, 2007; McGuire and others, 2007). For example, a survey of Indonesian households impacted by the 2004 Indian Ocean tsunami demonstrated that mortality was highest for the youngest and oldest age groups (Rofi and others, 2007). Younger populations, defined here as less

Table 1. Demographic characteristics for residential populations.

Population	Evacuation Zone	State of Hawai‘i Total (2000)	Tsunami-Zone Percentage[1]	State Percentage[1]	Maximum Community Percentage
Total Population	80,443	1,211,537	n/a	n/a	99%
Hispanic or Latino Population	7,784	87,699	10%	7%	26%
Race—White alone or in combination with one or more other races	43,181	476,162	54%[2]	39%[2]	98%
Race—Black or African American alone or in combination with one or more other races	2,061	33,343	3%[2]	3%[2]	14%
Race—American Indian and Alaska Native alone or in combination with one or more other races	2,209	24,882	3%[2]	2%[2]	8%
Race—Asian alone or in combination with one or more other races	29,741	703,232	37%[2]	58%[2]	95%
Race—Native Hawaiian and Other Pacific Islander alone or in combination with one or more other races	27,125	282,667	34%[2]	23%[2]	80%
Population under five years old	5,950	78,163	7%	6%	15%
Population over 65 years	8,763	160,601	11%	13%	40%
Female population	39,517	602,866	49%	50%	78%
Number of Households	26,854	403,240	n/a	n/a	99%
Renter-Occupied Households	14,358	175,352	53%	43%	99%
Single-mother Households	1,917	23,619	7%	6%	18%

[1]In-hazard percentages refer the percentage of individuals (or households for the last two rows) in the tsunami-evacuation of a specific demographic category. State percentages refer to the percentage of individuals (or households for the last two rows) in the State of a specific demographic category

[2]The sum of percentages by race will not sum to 100 percent, as individuals are able to report multiple race categories in Census Bureau reports.

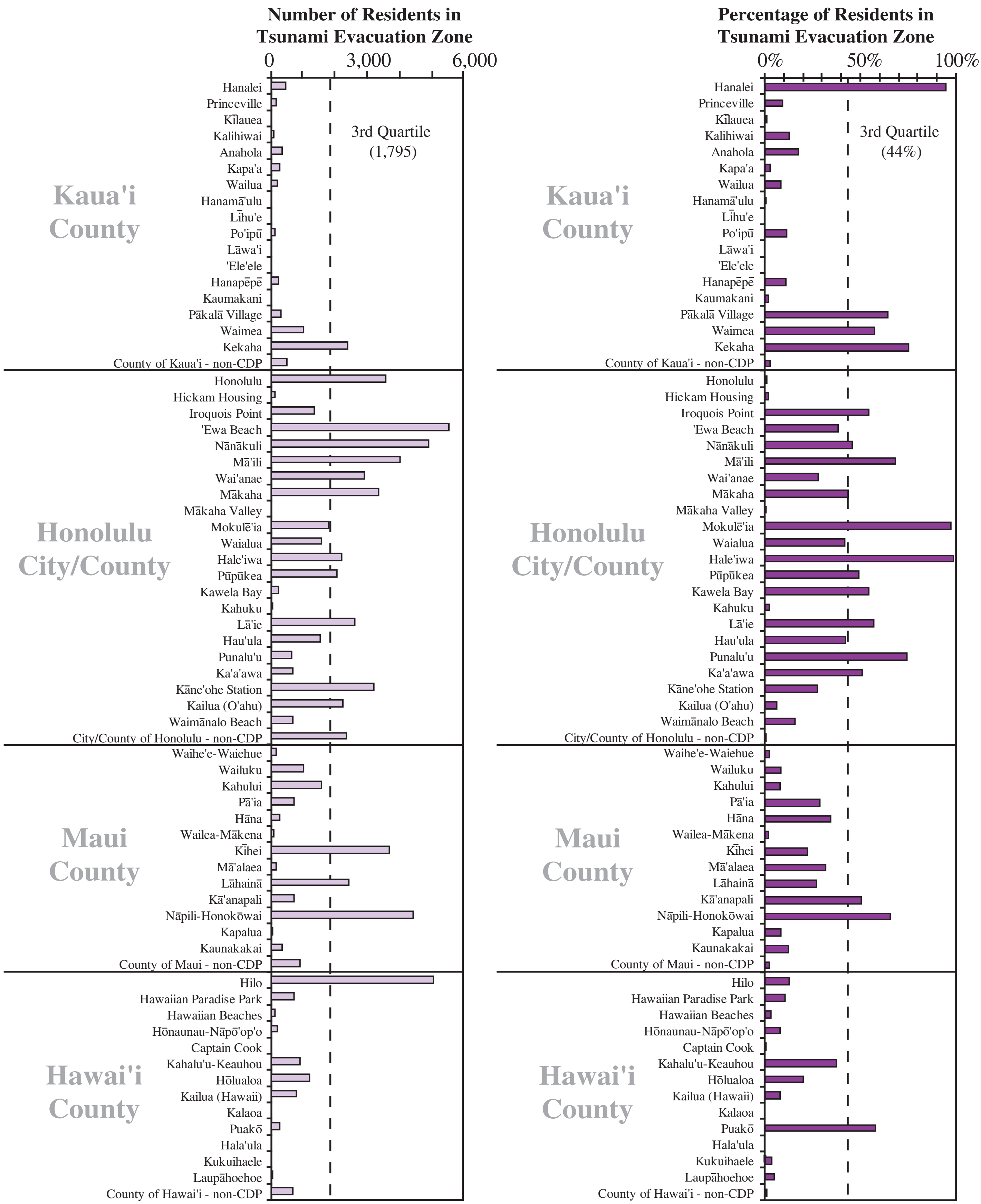

Figure 6. Number and percentage of residents in tsunami-evacuation zones, organized by census-designated place.

than 5 years in age, often require direction and assistance to evacuate due to their immaturity and size. They are also prone to developing post-traumatic stress disorders, depressions, anxieties, and behavioral disorders as a result of their inability to comprehend and process effects of a disaster (Balaban, 2006). Our results indicate that 7 percent of individuals in the tsunami-evacuation zone are under the age of 5 years, equal to the State percentage (table 1). For the 65 communities, the percentage of individuals in the tsunami-evacuation zone that are under the age of 5 years ranges from 0 to 15 percent, with maximum values found in Iroquois Point.

Older populations, defined here as over 65 years in age, are also disproportionately more vulnerable than other age groups. Research suggests the individuals aged 65 years or older may require assistance in evacuation due to potential mobility and health issues, are often reluctant to evacuate, may require special medical equipment at shelters (McGuire and others, 2007), and are more apt to lack social and economic resources to recover (Morrow 1999; Ngo 2001). Results indicate that 11 percent of individuals in the tsunami-evacuation zone are over 65, slightly lower than 13 percent for the entire State. For the 65 communities, the percentage of individuals in the tsunami-evacuation zone that are over the age of 65 ranges from 0 to 40 percent, with maximum values found in Līhuʻe.

Gender differences also influence an individual's sensitivity to a stressor (Enarson and Morrow 1998; Bateman and Edwards, 2002). Preliminary work by Oxfam (2005) in the wake of the 2004 Indian Ocean tsunami suggests that women had a disproportionately higher mortality rate. In general, research suggests that although women tend to be more risk-averse and more likely to respond to warnings than men, there are more documented reports after disasters of women with post-traumatic stress (Ollenberger and Tobin, 1998) and a higher incidence of abuse against women (Enarson, 1999). Women tend to have a higher risk perception and demonstrate higher preparedness planning, but also are more likely to be single parents or primary care givers and have lower incomes, special medical needs, and less autonomy. These aspects of heightened vulnerability issues for women to extreme natural events are believed to be reflections of broader cultural, political, and economic inequalities within a society (Morrow, 1999; Bateman and Edwards, 2002). Results indicate that 49 percent of individuals in the tsunami-evacuation zone are women, slightly lower than 50 percent for the entire State. For the 65 communities, the percentage of residents in the tsunami-evacuation zone that are female ranges from 0 to 78 percent, found in the non-CDP areas of Maui County. Single-mother households may have unique evacuation and recovery issues, as they are more likely to be poor and have fewer resources (Laska and Morrow, 2007). Results indicate that 7 percent of households in the tsunami-evacuation zone are single-mother households, similar to the 6 percent State total. For the 65 communities, the percentage of households in the tsunami-evacuation zone that are single-mother households ranges from 0 to 18 percent, found in Kahului.

Tenancy is another factor that influences individual sensitivity to stressors, as studies have shown that renters are less likely to prepare for catastrophic events than homeowners (Morrow 1999; Burby and others, 2003). Theories on why this is the case include higher turnover rates for renters may limit their exposure to hazard-related outreach efforts, renters typically have lower incomes and fewer resources to recover, renters may lack the motivation to invest in mitigation measures for property they don't own, owners may also lack this motivation because costs may be hard to recover, and many preparedness campaigns pay less attention to renters (Burby and others, 2003). After a disaster, renters also have little control over the speed with which rental housing is repaired or replaced (Laska and Morrow, 2007). Results indicate that 53 percent of households in the tsunami-evacuation zone are renter-occupied, higher than the 43 percent State average (U.S. Census Bureau, 2000). For the 65 communities, the percentage of households in the tsunami-evacuation zone that are renter-occupied ranges from 0 to 99 percent, with maximum values found in Hickam Housing, Iroquois Point, and Kāneʻohe.

In addition to certain age, gender, and tenancy characteristics, households of racial and ethnic minorities also tend to be more vulnerable to extreme events and have higher mortality rates (Morrow, 1999). This reflects not characteristics of the individual but of historic patterns of racial and ethnic inequalities within a society that result in minority communities more likely to have inferior public services, infrastructure and building stock (Laska and Morrow, 2007) and to be excluded from disaster planning efforts (Morrow, 1999). Minorities that speak a language other than the primary language of an area can also have higher vulnerability, as language barriers could hinder the effectiveness of awareness campaigns, evacuation procedures, and post-disaster recovery opportunities. Racial diversity is high for residents in the tsunami-evacuation zone and the dominant races are White (54 percent), Asian (37 percent), and Native Hawaiian and other Pacific Islander (34 percent). Percentages in table 1 and the accompanying database in the race categories do not sum to 100 percent because individuals were able to report multiple races in Census 2000.

Self-reported racial and ethnic characterizations for individuals in tsunami-evacuation zones largely mimic State-level characteristics (table 1). For example, 3 percent of the residents in tsunami-evacuation zones and 3 percent of residents in the State report themselves as Black or African American alone or in some combination with one or more other races. The only large differences between in-hazard zone percentages and State percentages were observed for individuals who reported their races as White or Asian. For those individuals that report their race as White alone or in combination with one or more other races, the in-tsunami-zone percentage (54 percent) is higher than the State average (37 percent), suggesting that this demographic group is more likely to be living in low-lying areas along the coast. The opposite is true for individuals that report their race as Asian alone or in some combination with one or more races. Here, the in-tsunami-zone percentage (37 percent) is lower than the State average (58 percent), suggesting that this demographic group is more likely to live in-land.

Employee Populations

Results indicate that 67,113 people are employed at 5,779 businesses located in Hawaiian tsunami-evacuation zones, representing 11 percent of the employees in the State of Hawai‘i. The median value for the percentage of employees working in the tsunami-evacuation zones of CDPs is 15 percent for the region and the third quartile (75th percentile) is 54 percent. Similar to residential populations, the amount (fig. 7*A*) and percentage (fig. 7*B*) of employee populations in tsunami-evacuation zones vary considerably in the State of Hawai‘i. Again, certain communities such as Honolulu and Hilo have high numbers of employees in tsunami-evacuation zones (9,725 and 9,444, respectively) that represent lower percentages of total employees (4 percent and 37 percent, respectively). Other communities have much lower numbers of employees in tsunami-evacuation zones, including Hanalei (862 employees), Iroquois Point (225 employees), and Punalu‘u (109 employees), but, in each of these cases, these employees represent 100 percent of the community’s workforce.

Dependent Populations

Results indicate that there may be significant numbers of dependent-population facilities in the tsunami-evacuation zone (table 2). The highest number of dependent-population facilities in the tsunami-evacuation zone were outpatient-care facilities (242), followed by schools (41), child day-care facilities (19), adult residential-care facilities (7), and psychiatric and substance-abuse hospitals (4). On the basis of these results, a follow-up study to confirm the location and determine the size of these dependent populations may be warranted.

Results of the dependent-populations analysis should be considered preliminary for four reasons. First, no fieldwork was conducted to verify the location accuracy of the businesses. Second, the results summarize the number of facilities, not the number of individuals in the facility, and no extra weighting is given to larger facilities. Third, in working with the infoUSA Employer Database, we learned that similar facilities were sometimes coded differently. For example, a facility with the word “Hospital” in its name was coded as a hospital in some cases but as an outpatient-care facility in other cases. Fourth, we also learned that the category “Schools” includes not only elementary and secondary education facilities, but also dive, parachute, and dance schools. Therefore, results should not be considered a definitive assessment of the distribution of facilities, but instead should be considered preliminary for the purposes of initiating discussions and future analytical efforts. On the basis of this preliminary study, although we believe the infoUSA Employer Database in its raw form is effective at determining regional trends, ground-truthing is necessary before the data can be used in an operational or tactical sense.

Table 2. Summary of the amount and percentage of dependent-population facilities in tsunami-evacuation zones.

Facility	Evacuation Zone	State Total	Percentage
Adult-residential-care facilities	7	131	5%
Child-day-care facilities	19	215	9%
Correctional facilities	0	10	0%
Hospitals	0	21	0%
Outpatient-care facilities	242	3,523	7%
Psychiatric and substance abuse hospitals	4	32	13%
Schools	41	518	8%

Tourist Populations

Results indicate that there are 152 hotels (representing 49 percent of all hotels in Hawai‘i) and 50,174 average daily visitors (representing 44 percent of overnight tourists) in the various tsunami-evacuation zones of Hawai‘i. The median ADV value of zero and third quartile ADV value of 529 indicate that most communities do not have high numbers of overnight guests. In other words, the presence of overnight guests is not evenly distributed across the study area and most overnight guests are clustered in approximately one-third of the 65 communities in this study (fig. 8A). The largest ADV numbers are in Honolulu (10,940), Kā‘anapali (8,914), and Puakū (5,054). Similar to residential-population numbers, the low overall ADV values found in most communities translate into high percentages of overnight tourists occupying the tsunami-evacuation zones of these communities, demonstrated by a high third-quartile value of 75 percent (fig. 8B).

Results indicate that there are significant numbers of public venues in tsunami-evacuation zones that likely attract high numbers of tourists, including 240 parks, 121 religious-service facilities, 42 historic places, 21 shopping centers, 7 museums, and one aquarium (table 3). The 121 religious-service facilities in the tsunami-evacuation zone present both opportunities and challenges for the emergency-management community. An obvious challenge is the large number of individuals that would be in a tsunami-evacuation zone if an event were to strike during a religious service. The high number of religious organizations in tsunami-evacuation zones, however, presents an education/outreach opportunity for county and State emergency managers to work with religious leaders in disseminating tsunami-hazard and community-resilience education materials developed by the emergency-management community.

Similar concerns expressed previously on the use of the infoUSA Employer Database apply to public venues. For example, in working with the data, we realized that a wide range of businesses are classified as “colleges and universities,” including not only 2- and 4-year colleges, technical schools, and trade schools, but also flight schools, and even

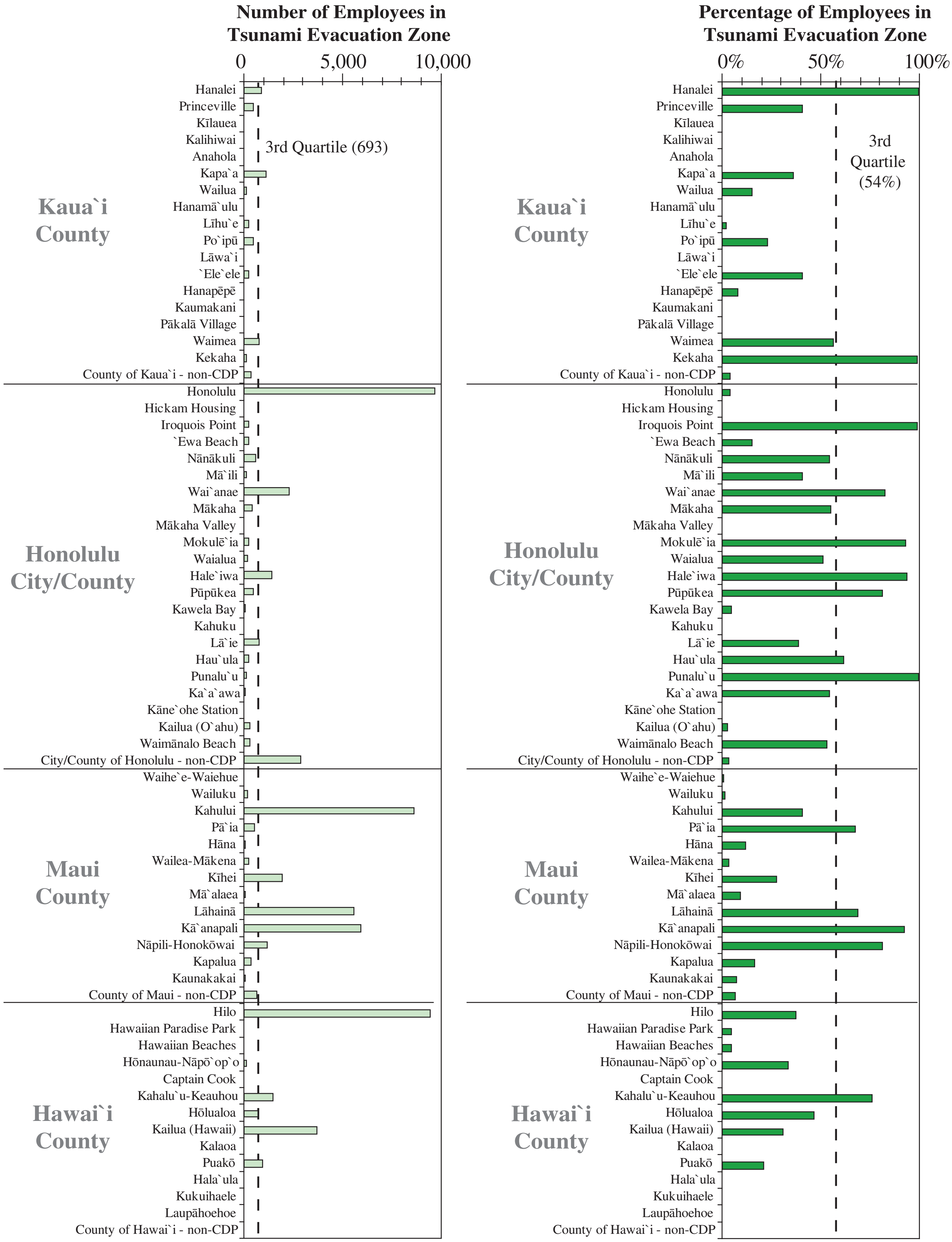

Figure 7. Number and percentage of employees in tsunami-evacuation zones, organized by census-designated place.

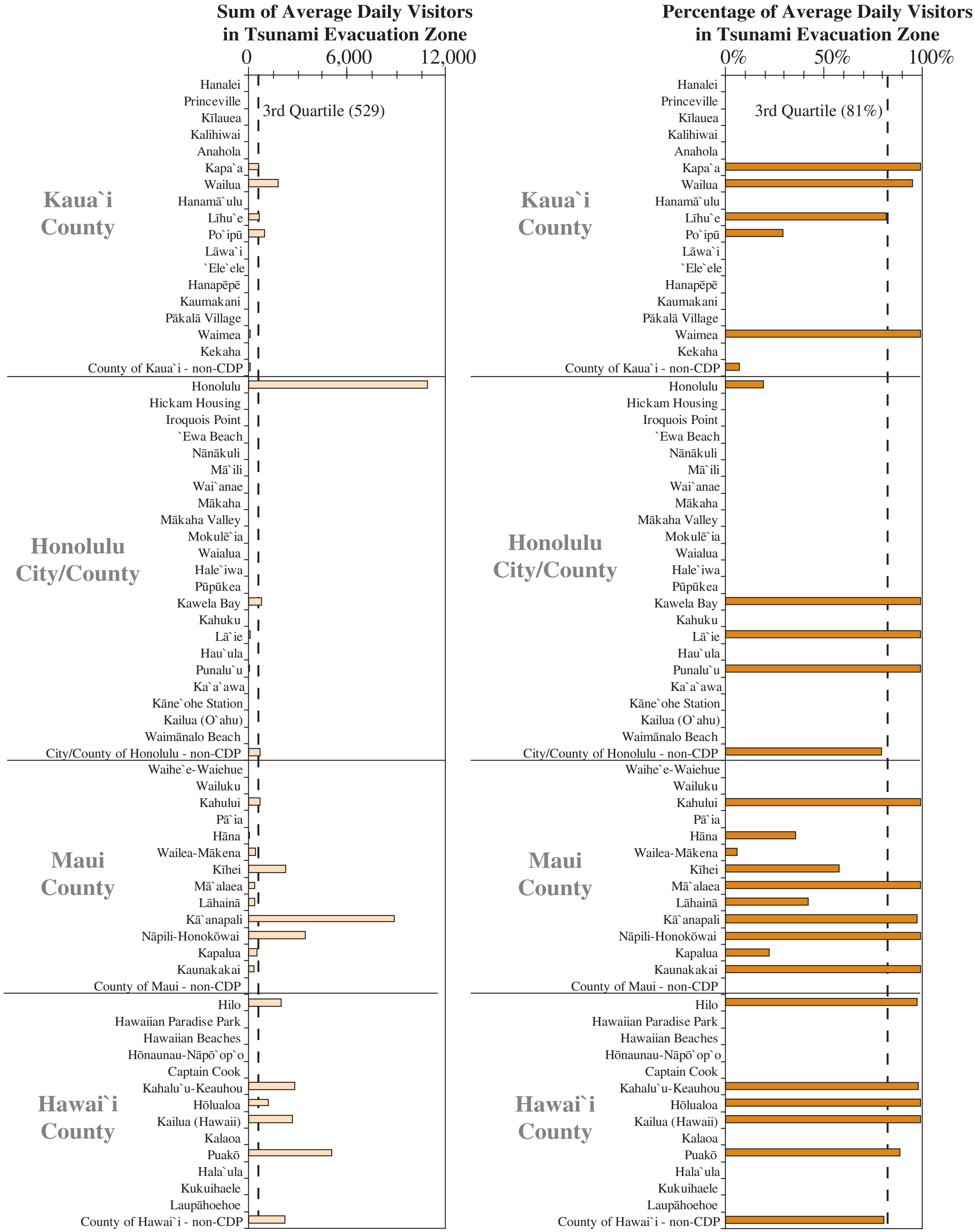

Figure 8. Sum and percentage of hotel average daily visitor (ADV) estimates, organized by census-designated place.

Table 3. Summary of the amount and percentage of public-venue locations in tsunami-evacuation zones.

Public Venue	Evacuation Zone	State Total	Percentage
Aquariums	1	1	100%
Botanical gardens	1	9	11%
Colleges and universities	3	57	5%
Historical place	1	7	14%
Historic place (NRHP)[1]	42	190	22%
Libraries	8	89	9%
Museums	7	22	32%
Parks	240	1567	15%
Religious organizations	121	1083	11%
Shopping centers and malls	21	91	23%
Sporting facilities	1	3	33%
Theaters	5	23	22%
Zoos	0	3	0%

[1]NRHP refers to the National Registry of Historic Places.

dance academies. Therefore, the "Colleges and Universities" category should not be considered a summation of the traditional use of this term, namely two- and four-year colleges.

Economic Assets

Results indicate that total tax parcel value (minus exemptions) for parcels in tsunami-evacuation zones is approximately $36.1 billion (table 4), representing 18 percent of the state total, and that the exposure and sensitivity of communities with regards to total tax parcel value (minus exemptions) varies significantly across the State of Hawai‘i (fig. 9). The median value for exposed, total tax-parcel value (minus exemptions) per CDP is approximately $186 million and the third quartile per CDP is $517 million. Certain communities, such as Honolulu and Kā‘anapali, have over $3 billion in total tax parcel value (minus exemptions) in tsunami-evacuation zones. As was the case with other socioeconomic data, the high amounts of exposed tax parcel value in communities like Honolulu (approximately $4.6 billion) represent small percentages (8 percent) of the community's tax base. Although many communities have relatively low amounts of tax parcel value in the tsunami-evacuation zones, the exposed parcels represent a high percentage of a community's tax base, a finding also observed in the distribution of residential and employee populations. Communities such as Hanalei, Mokulē‘ia, Hale‘iwa, Kawela Bay, and Punalu‘u are near the third quartile value of $517 million, but in each case, almost 100 percent of their tax base is in the tsunami-evacuation zone.

Results indicate that there are 5,779 businesses with 67,113 employees that generate over $10 billion in sales volume in tsunami-evacuation zones of Hawai‘i, representing 11 percent of all businesses, employees, and generated sales volume in Hawai‘i (table 4). The percentages of exposed businesses, employees, and sales volume demonstrate high correlations amongst each other; therefore, following past research (Marshall, 1989) that suggests that employee distributions are the best indicator for characterizing economic conditions, we use the distribution of employees to describe community economic profiles in the State of Hawai‘i. Figure 7 was presented earlier to visualize variations in the amount and percentage of employees in tsunami-evacuation zones. As previously stated, high numbers of employees in tsunami-evacuation zones represent significant evacuation issues for local and State emergency managers. However, high percentages of employees in tsunami-evacuation zones represent economic fragility for a community, as unemployment could increase dramatically overnight if a tsunami injures or kills employees or if it damages or destroys businesses. Even if a business escapes damage or physical disruption from an extreme event, it may still experience significant customer and revenue loss if the neighborhood and other businesses around it are damaged, leading customers to shop elsewhere. Neighborhood effects have been found to be especially important for retailers that rely on foot traffic (Chang and Falit-Baiamonte, 2002), a potentially significant issue for tourist-related retail along the Hawaiian coast. Therefore, knowing where there are high amounts and percentages of employees helps identify potential economic recovery issues.

Results indicate that larger communities, such as Honolulu and Hilo, have significant numbers of employees in evacuation zones but these numbers represent a small proportion of the economies of these locales (fig. 7). Smaller communi-

Table 4. Summary of the amount and percentage of economic assets in tsunami-evacuation zones.

Economic Asset	Evacuation Zone	State of Hawai‘i Total	Tsunami-Zone Percentage	Community Median Percentage	Community Maximum Percentage
Businesses	5,779	50,676	11%	25%	100%
Employees	67,113	560,043	12%	15%	100%
Sales volume (in U.S. dollars)	$10,106,230,000	$89,379,406,000	11%	14%	100%
Total tax-parcel value minus exemptions (in U.S. dollars)	$36,095,041,411	$201,157,457,407	18%	26%	99%

Figure 9. Amount and percentage of total parcel value (minus exemptions), organized by census-designated place.

ties, such as Hanalei and Punalu‘u, may have much smaller numbers of employees in evacuation zones, but face relatively larger threats to their economies from a tsunami.

The distribution of employees by business type (fig. 10) indicates that the highest numbers of employees in the State of Hawai‘i are in accommodation and food services (15 percent), health care and social assistance (13 percent), and retail trade (13 percent). The percentage of employees in the accommodation and food services sector is almost double the national average of 8.3 percent (2005 value) for the same industry sector (Bureau of Labor Statistics, 2007b), reflecting the dominance of the tourism sector in the State of Hawai‘i economy. The employee distribution for businesses in the tsunami-evacuation zone largely mimics the distribution for businesses in the entire State. The only deviations from the State-level distribution to the evacuation-zone businesses are the increase in the accommodation and food services businesses (from 15 percent to as much as 27 percent) and the decrease in health care and social assistance businesses (from 13 percent down to 6 percent). Again, the results reaffirm that tourism-related businesses dominate tsunami-prone areas (27 percent of businesses compared to a national average of 8.3 percent) and that most accommodation and food services businesses in the State occupy low-lying areas near the coastline.

Critical and Essential Facilities

Results indicate that there are several critical and essential facilities in tsunami-evacuation zones (table 5). The highest number of facilities in tsunami-evacuation zones is offices of physicians (231 offices). The low number of exposed hospitals (0) and outpatient-care centers (7), but high number of exposed physician offices, suggests that community hospitals may be able to handle casualties during the immediate response phase of a disaster; however, communities may experience difficulties in maintaining medical services during the longer-term recovery phase. Long-term community recovery may also be hampered by the potential loss of the numerous essential facilities in tsunami-evacuation zones, including banks and credit unions (50), government offices (99), grocery stores (35) and gas stations (23). Due to the terms of use of the infoUSA Employer Database, we are unable to provide maps of critical and essential facilities in relation to tsunami-evacuation zones. Interested parties should contact Hawai‘i State Civil Defense or the Hawai‘i Office of Planning for additional information related to this dataset.

In most cases, the relative percentages are low for most categories when comparing facilities in tsunami-evacuation zones to State totals. A logical next step for analysis is to determine the locational accuracy of critical and essential facilities that are highlighted as being in tsunami-evacuation zones, due to concerns expressed previously on the accuracy of the infoUSA Employer Database. Another area for further investigation is the redundancy of facility functions in an area. For example, results presented here may indicate that a community’s police stations are in the tsunami-evacuation zone.

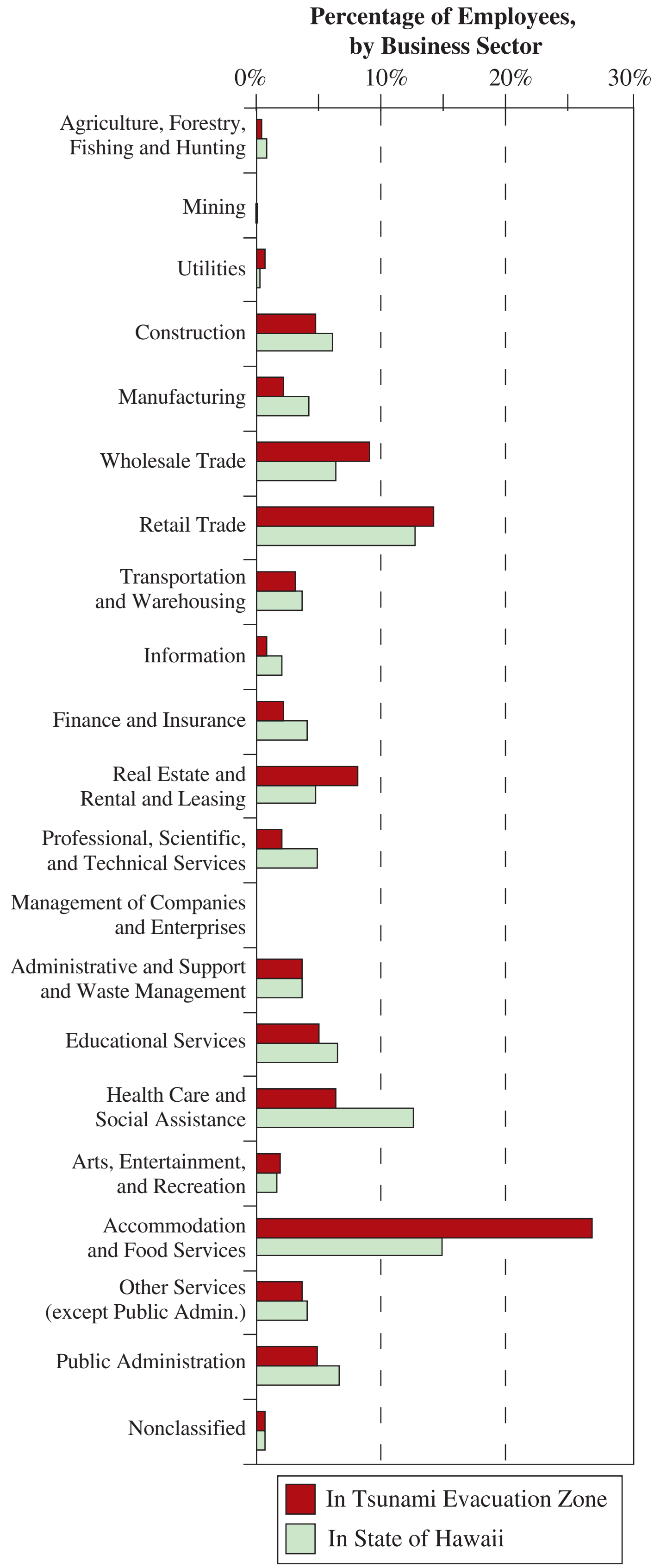

Figure 10. Types of businesses in tsunami-evacuation zone, organized by North American Industry Classification code.

If a neighboring community also has the same issue, then the ability to maintain order for the region is compromised even more. However, if a neighboring town has similar facilities that are not in tsunami-evacuation zones, resources could be shared between communities.

Composite Indices of Community Exposure and Sensitivity

To synthesize the numerous datasets reported here and determine which communities are the most vulnerable to tsunamis in Hawai‘i, composite indices of exposure and sensitivity were created by adding the normalized values of developed land, residents, employees, hotel ADV values, and total parcel value (minus exemptions). The composite exposure index is based on the amount of each attribute, whereas the composite sensitivity index is based on the percentage of each attribute for a geographic unit. Table 6 summarizes the composite exposure and sensitivity values (each with a range from 0 to 5) for the 65 communities and the non-CDP areas of the four counties. Figure 11 provides the same results in a map-based format to better visualize spatial variations in composite scores across the state. Note, in figure 11, colored points near the county names represent the scores for the non-CDP portions of each county. In both table 6 and figure 11, higher composite values indicate higher relative exposure or sensitivity values. These scores are meaningless for individual communities and only provide insight on the relative vulnerability of communities to tsunamis in Hawai‘i. In general, high composite exposure scores are found in Honolulu, Hilo, and the western shore of Maui island (fig. 11). No spatial trend is discernible for composite sensitivity scores, as low and high values are found on each island (fig. 11).

A frequency histogram illustrates the distribution of composite exposure and sensitivity values (fig. 12), with the x-axis showing the sum of the five normalized values with a range of 0 to 5, summarized here in 0.5 increments, and the y-axis noting the number of communities for each category. Results portrayed in table 6, figure 11, and figure 12 indicate that most communities have low composite exposure and sensitivity values. Exposure values are skewed heavily to the lowest bin of 0.0 to 0.5, where 58 of the 69 geographic units have composite exposure values of 1.0 or less, demonstrated in figure 11 by the numerous green dots that represent scores less than 1.0. It is possible that a community in this lowest bin may have a high number of exposed assets in one category (for example, residents), but overall, a low composite exposure score indicates that most of its assets are not in tsunami-prone areas. The highest composite exposure value is 4.13, denoting the city of Honolulu on the island of O‘ahu (fig. 11). The high skewness of the distribution to the lowest composite-score bins (less than 1.0) indicates that the community assets exposed to tsunamis is consistently and significantly higher in Honolulu than in the other communities, expressed by the high number of green points in figure 11.

Unlike the composite relative exposure values, the composite relative sensitivity values do not skew as strongly to the lowest bin and have a bimodal distribution, with the highest peak in the 0.0 to 0.5 bin and a secondary peak in the 2.0 to 2.5 bin (fig. 12). The highest composite sensitivity value is 4.63 for the community of Punalu‘u, located on the northeastern coast of O‘ahu (fig. 11). A score of 4.63 indicates that the percentage of community assets in the tsunami-evacuation zone is consistently high. Punalu‘u is a small community where 74 percent of its residents, 100 percent of its employees and average daily visitors, 91 percent of its developed land, and 94 percent of its total tax value are in the tsunami-evacuation zone. The large number of communities with scores between 2.0 and 4.0 indicates, however, that Punalu‘u is not as anomalous for composite sensitivity values, as Honolulu is for composite exposure values.

As noted earlier, certain communities have high relative exposure values and others have high relative sensitivity. Figure 13 graphically portrays this by showing composite exposure and sensitivity values back to back for each community. Although both categories share a common data range of 0 to 5, the exposure scale is reversed for easier visual comparisons. As noted elsewhere in this report, some cities have high expo-

Table 5. Summary of the amount and percentage of critical- and essential-facilities in tsunami-evacuation zones.

Critical facilities	Evacuation Zone	State Total	Percentage
Civil-defense facilities	0	7	0%
Fire stations	8	42	19%
National-security facilities	6	43	14%
Police stations	5	79	6%
Ambulance services	4	8	50%
Hospitals	0	21	0%
Outpatient-care centers	7	110	6%
Offices of physicians	231	3,405	7%
Electrical facilities	2	11	18%
Public-works facilities	2	10	20%
Gas facilities	1	2	50%
Radio and television facilities	4	42	10%
Waste-water facilities	1	8	13%
Water and sewer facilities	3	10	30%
Essential facilities			
Banks and credit unions	50	415	12%
Courts and legal offices	6	70	9%
Gas stations	23	156	15%
Government offices	99	629	16%
International-affairs offices	0	31	0%
Groceries	35	243	14%

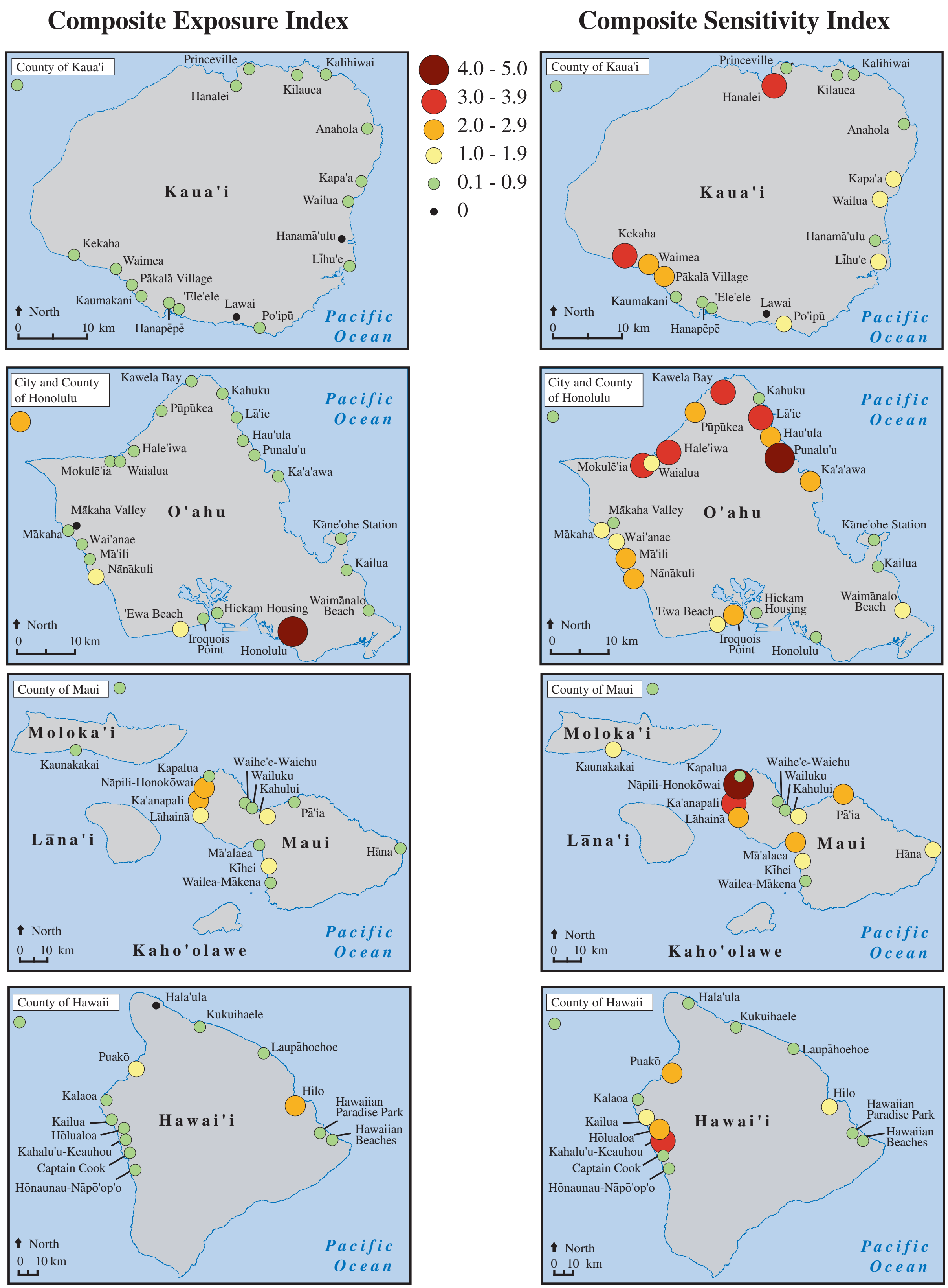

Figure 11. Map of composite exposure and sensitivity values. Values range from 0 (lowest) to 5 (highest) and are the sum of the normalized values (each from 0 to 1) of residents, employees, developed land, parcel value, and average daily visitors in each community.

Table 6. Composite exposure and sensitivity values for communities in the tsunami-evacuation zone.

Range	Composite Exposure Values		Composite Sensitivity Values	
4.0 to 5.0	Honolulu		Nāpili-Honokōwai	Punalu‘u
3.0 to 3.9			Hanalei Hale‘iwa Kā‘anapali Kahalu‘u-Keauhou	Kawela Bay Kekaha Lā‘ie Mokulē‘ia
2.0 to 2.9	Hilo Honolulu City/County (non-CDP) Kā‘anapali Nāpili-Honokōwai		Hau‘ula Hōlualoa Iroquois Point Ka‘a‘awa Lāhainā Mā‘alaea Mā‘ili	Nānākuli Pā‘ia Pākalā Village Puakō Pūpūkea Waimea
1.0 to 1.9	‘Ewa Beach Kahului Kīhei Nānākuli Lāhainā Puakō		‘Ewa Beach Hāna Hilo Kapa‘a Kahului Kailua (Hawai‘i) Kaunakakai Kīhei	Līhu‘e Mākaha Po‘ipū Waialua Wai‘anae Wailua Waimānalo Beach
0 to 0.9	Anahola Captain Cook ‘Ele‘ele Hala‘ula Hale‘iwa Hāna Hanalei Hanamā‘ulu Hanapēpē Hau‘ula Hawai‘i County (non-CDP) Hawaiian Paradise Park Hawaiian Beaches Hickam Housing Hōnaunau-Nāpō‘op‘o Iroquois Point Ka‘a‘awa Kahalu‘u-Keauhou Hōlualoa Kahuku Kailua (Hawai‘i) Kailua (O‘ahu) Kalaoa Kalihiwai Kāne‘ohe Kapa‘a Kapalua Kawela Bay Kaua‘i County (non-CDP) Kaumakani	Kaunakakai Kekaha Kīlauea Kukuihaele Lā‘ie Laupāhoehoe Lāwa‘i Līhu‘e Mā‘alaea Maui County (non-CDP) Mā‘ili Mākaha Mākaha Valley Mokulē‘ia Pā‘ia Pākalā Village Po‘ipū Princeville Punalu‘u Pūpūkea Waialua Wai‘anae Waihe‘e-Waiehu Wailea-Mākena Wailua Wailuku Waimānalo Beach Waimea	Anahola Captain Cook ‘Ele‘ele Hala‘ula Hanamā‘ulu Hanapēpē Hawai‘i County (non-CDP) Hawaiian Beaches Hawaiian Paradise Park Hickam Housing Hōnaunau-Nāpō‘op‘o Honolulu Honolulu County (non-CDP) Kahuku Kailua (O‘ahu) Kalaoa Kalihiwai	Kāne‘ohe Kapalua Kaua‘i County (non-CDP) Kaumakani Kīlauea Kukuihaele Maui County (non-CDP) Laupāhoehoe Lāwa‘i Mākaha Valley Princeville Waihe‘e-Waiehu Wailea-Mākena Wailuku

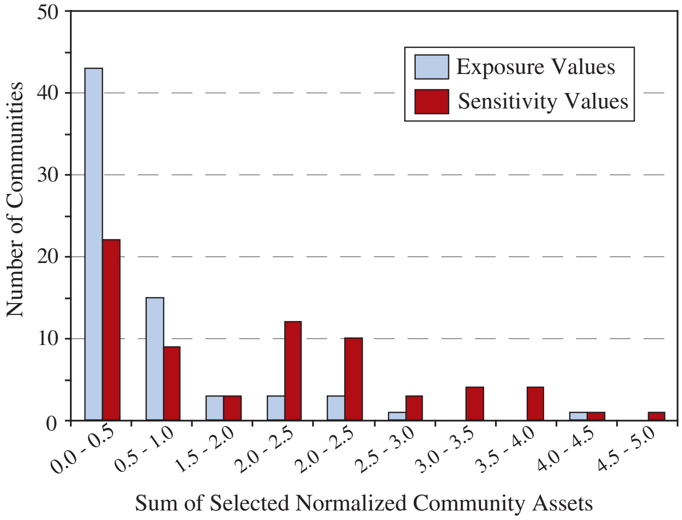

Figure 12. Frequency histogram of the sum of normalized exposure and sensitivity indices.

sure values but low sensitivity values; for example, the city of Honolulu has the highest composite exposure value (4.13), but one of the lowest composite sensitivity values (0.37). Similar examples of this characteristic include the community of Hilo and the non-CDP portions of Honolulu County. In contrast, other communities have low exposure values but high sensitivity values; for example, the community of Punaluʻu has the highest composite sensitivity value (4.63) but one of the lowest exposure values (0.17). Other examples of this include the communities of Kahaluʻu-Keauhou, Puakō, Iroquois Point, Mokulēʻia, Haleʻiwa, Lāʻie, Hanalei, Pāʻia, and Kekaha. The few communities that have relatively high composite values in both categories include the communities of Kahului, Kīhei, Kāʻanapali, and Nāpili-Honokōwai.

To provide some insight on which communities have the highest combined exposure and sensitivity to tsunamis, we normalized the composite exposure and sensitivity values to maximum values found in each category (thereby creating a common data range of zero to one and minimizing any bias between categories) and then added the normalized indices (fig. 14). The final index is, again, numerically meaningless for a given community but does offer a glimpse of relative exposure and sensitivity throughout the region. The communities with the highest combined values are Nāpili-Honokōwai, Kāʻanapali, Honolulu, Punaluʻu, Haleʻiwa, and Hilo. Some communities are primarily vulnerable to tsunamis due to the exposure of their assets (for example, Honolulu), whereas others are vulnerable due to higher community sensitivity to the potential losses (for example, Punaluʻu and Haleʻiwa).

There are several reasons that this relative assessment of vulnerability to tsunamis should only be considered a first approximation and not a final statement. First, these calculations focused only on a selection of variables—developed land, residents, employees, parcel values, and hotel ADVs. Follow-up studies of community vulnerability should include the exposure and sensitivity of additional community assets, such as cultural resources or natural resources. Second, the final index assumes an equal weighting of community exposure and sensitivity factors. There is a dearth of current research on the relative importance of either in determining the overall vulnerability of a community; however, future research may suggest that a different weighting is used. Third, these calculations do not include variations in community resilience, another key component of vulnerability. The ability of a community to withstand, absorb, adapt to, and recover from losses defines its resilience, and—with other conditions remaining the same—greater resilience lowers a community's vulnerability to extreme events. For example, if two communities have identical community assets in tsunami-prone land, but one has a tsunami education programs, a well-rehearsed evacuation plan, a coordinated response network, redundant critical infrastructure, and a holistic post-disaster recovery plan, then that community would probably have greater resilience. Despite their similar asset distributions, the same extreme natural event would mean a short-term crisis in the more resilient community and a longer-term disaster in the other community

Statistical Relationship to Land-Cover Data

Simple-linear regression analyses were performed to test the hypothesis that the distribution of assets in a community depends on how much of a community's land, regardless of type, is in the tsunami-evacuation zone and were done for values of exposure (the amounts of land compared to the amounts of various assets in tsunami-evacuation zones) and of sensitivity (the percentages of land compared to the percentage of various community assets in tsunami-prone areas). Relationships between land-cover data and socioeconomic data are considered significant if statistically-derived *p*-values are less than 0.05.

Results indicate that some, but not all relationships are significant (table 7). For exposure values, the relationships between the amount of tsunami-prone land in a community and the amount of most community assets are not statistically significant, including residents ($p = 0.70$), employees ($p = 0.41$), and hotel visitors ($p = 0.16$). The relationships are significant between the amount of land and the amount of developed land ($p << 0.01$) and total parcel value ($p = 0.02$); however, low explained variance (r^2) values for these assets (0.28 for developed land and 0.08 for parcel values) suggest that the relationships, although statistically significant, are not strong.

For sensitivity values, relationships are statistically significant between the percentage of tsunami-prone land of a community and the percentage of most community assets, including developed land ($p << 0.01$), residents ($p << 0.01$), employees ($p << 0.01$), and parcel value ($p << 0.01$). The only exception is the percentage of a community's hotel visitors, which is not significantly related to the percentage of tsunami-prone land ($p = 0.92$). Unlike the significant exposure relationships, r^2 values for sensitivity comparisons are moderately

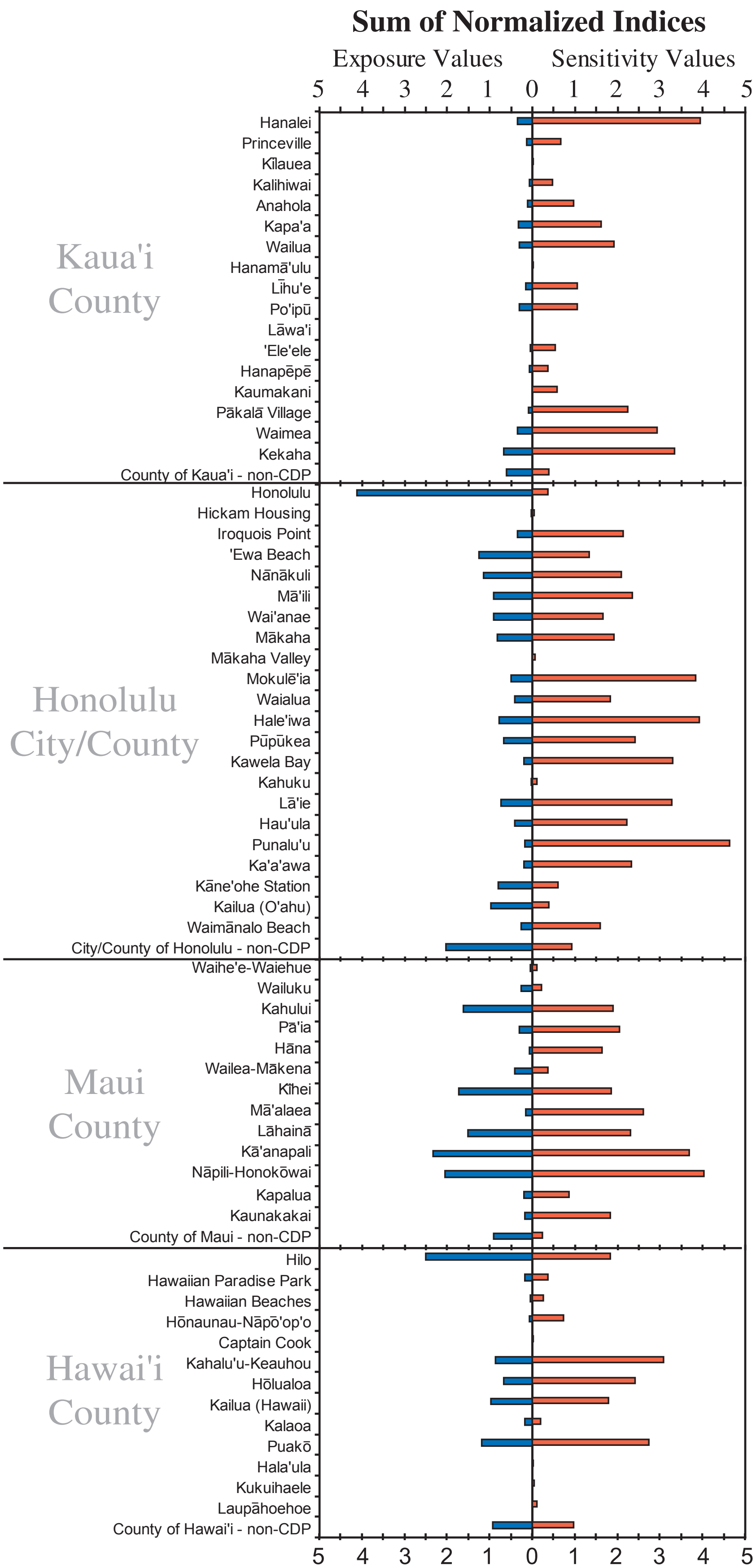

Figure 13. Comparison of normalized exposure and sensitivity indices.

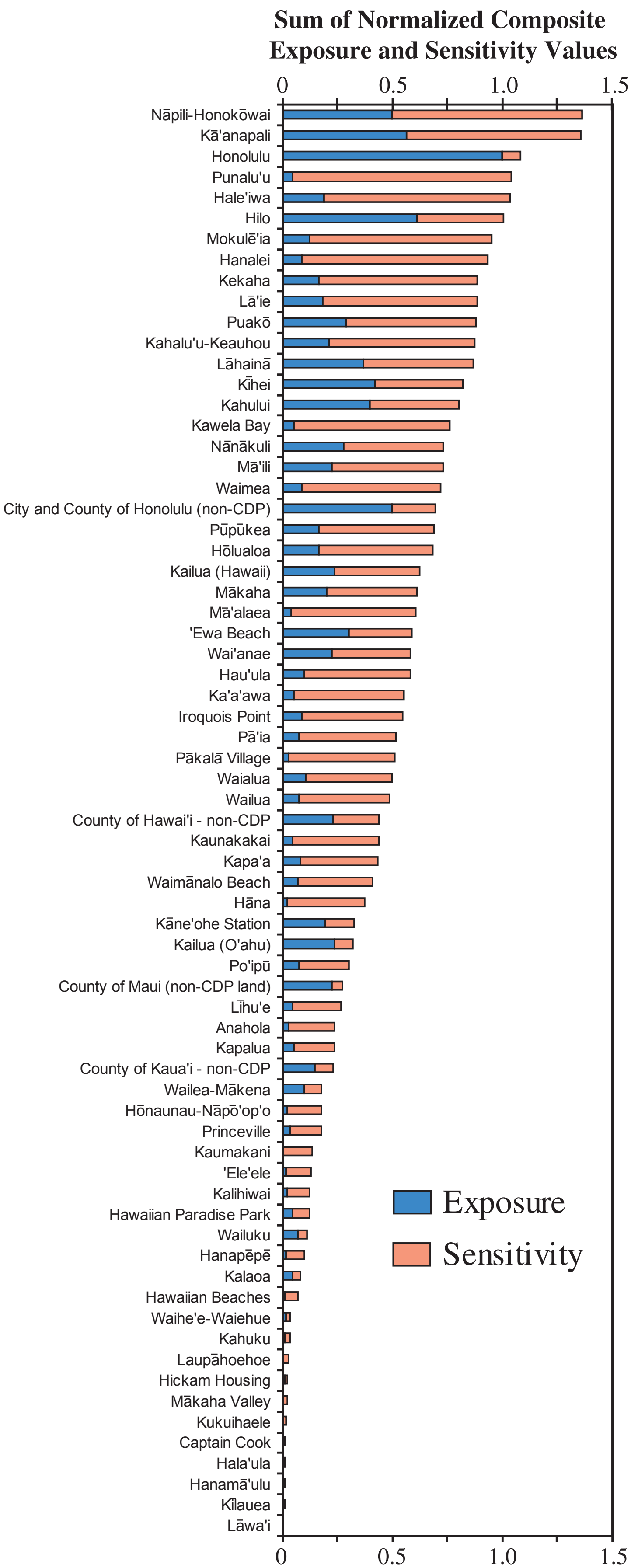

Figure 14. Sum of normalized exposure and sensitivity indices for selected community assets.

strong, ranging from 0.34 for employees to as much as 0.73 for residents.

Two graphs are provided to help visualize the differences between the non-significant and significant relationships reported above. Figure 15*A* is a scatter-plot comparing the amount of community land in tsunami-evacuation zones with the amount of residents in tsunami-evacuation zones (both normalized for visual ease) for the 69 geographic units. No statistically significant relationship exists between the two datasets ($p = 0.70$, $r^2 \leq 0.01$) and this is evident in figure 15*A* by the lack of any discernible trend in the points relative to the calculated regression line. Conversely, figure 15*B* shows the percentage of community land compared to the percentage of residents, in which a statistically significant relationship is present ($p << 0.01$). An r^2 value of 0.73 is reflected in a distinct clustering of points around the calculated regression line.

These results suggest that the amount of land in the tsunami-evacuation zone of a CDP does not have an important influence on the quantity of most assets—such as number of residents, number of employees, or hotel visitors—found in the tsunami-evacuation zones of the 65 Hawaiian communities or the non-CDP land of the four counties. In other words, two communities with the same amount of tsunami-prone land have made, and possibly still are making with new development, different land-use decisions on how much and what kind of development is in these threatened areas. The tsunami is the physical trigger that damages buildings and injures people, but the cumulative set of land-use decisions made over long periods sets the stage for these losses by creating unsafe conditions (Weichselgartner, 2001).

Results do show that the percentage of a community's land that is in tsunami-prone areas increases the percentage of its assets—such as the percentage of a community's workforce—located in the hazard zone. These findings suggest that there are few common patterns of asset distribution in the tsunami-evacuation zone from community to community, but consistency within individual communities. Consequently, knowing the amount of tsunami-prone land in a community does not indicate the level of community exposure, but knowing how much of a community's total land is located in a tsunami-prone area provides some insight on how sensitive a community is to tsunamis.

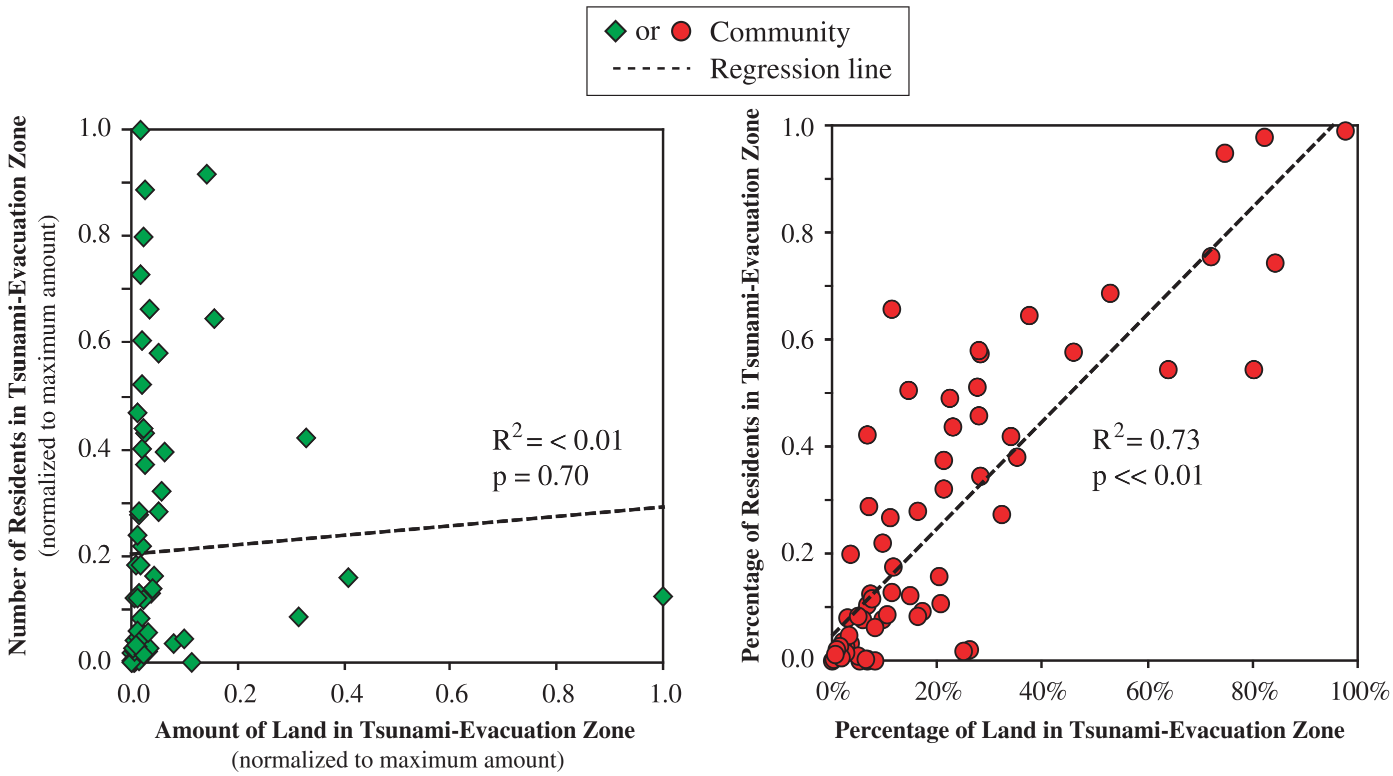

Figure 15. Scatter-plots comparing the distribution of land and of residents in relation to tsunami-evacuation zones.

Summary

Data and graphs presented in this report are provided to support a collaboration of the State of Hawai‘i Department of Defense Civil Defense Division, the State of Hawai‘i Office of Planning, the Pacific Disaster Center, and the USGS that focuses on improving understanding of community vulnerability to tsunamis in Hawai‘i. The purpose of the assessment was to characterize the landscape in tsunami-evacuation zones of the State of Hawai‘i and to compare community exposure and sensitivity, based on various socioeconomic attributes, to tsunamis.

Results indicate that there are significant variations in community exposure and sensitivity to tsunami hazards, with regards to the distribution of developed land cover, populations, economic assets, and critical facilities. Some communities, such as Honolulu and Hilo, have high exposure to tsunamis, because they have large amounts of their assets in tsunami-prone land; however, these large amounts represent a small percentage of the community. Other communities, such as Punalu‘u and Hanalei, are considered highly sensitive to tsunamis, where small amounts of assets in tsunami-prone areas represent large percentages of a community’s total. It is up to policymakers, land-use managers, emergency managers, nonprofit organizations, and private citizens to determine where to allocate limited risk-reduction resources and attention—to the communities with high loss potentials, to communities that may be incapable of adapting to the loss of significant percentages of their assets, or to a specific demographic or economic sector. Results also indicate that the level

Table 7. Statistical results for simple linear regression analyses comparing the amount of land and the amount of selected community assets.

Regression significance between land-cover with:	Exposure Values				Sensitivity Values			
	R	*R*²	*F*[1]	*p*	*R*	*R*²	*F*[1]	*p*
Developed land	0.53	0.28[1]	25.80	<< 0.01	0.85	0.72[1]	172.05	<< 0.01
Residents	0.05	<0.01	0.15	0.70	0.86	0.73[1]	182.18	<< 0.01
Employees	0.10	0.01	0.68	0.41	0.58	0.34[1]	34.00	<< 0.01
Hotel visitors	0.17	0.03	2.04	0.16	0.01	< 0.05	0.01	0.92
Total parcels value	0.29	0.08[1]	6.16	0.02	0.68	0.46[1]	57.38	<< 0.01

[1]A regression relationship is considered significant at $p < 0.05$ if $F > 3.98$, as $F_{0.05(1),1,67} = 3.98$.

of community-asset exposure to tsunamis is not determined by the amount of land in tsunami-evacuation zones. Community sensitivity, however, is related to the percentage of a community's land in the hazard-prone areas.

Information presented in this report will further the dialogue on reducing risk to tsunami hazards in Hawai‘i and help identify future preparedness, mitigation, recovery planning, and outreach activities within the coastal communities and economic sectors of the State of Hawai‘i. Follow-up studies to document community resilience would complement this report and provide the State of Hawai‘i with a more complete picture of community vulnerability to tsunamis. In addition, results of this study may also help public officials determine where site-specific risk assessments and more-detailed tsunami-inundation modeling efforts may be warranted to further detail the threats posed by tsunamis to coastal communities in Hawai‘i.

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Glossary

Dependents—Individuals who temporarily reside in facilities where they would be dependent on external assistance to evacuate and recover, including adult residential care, child day care, correctional facilities, hospitals, outpatient-care centers, psychiatric and substance-abuse hospitals, and schools.

Exposure—The first component of vulnerability, focusing on the amount of an asset (for example, the number of residents of a town) within a tsunami-evacuation zone.

Resilience—The third component of vulnerability, focusing on a community’s ability to withstand, absorb, adapt to, and recover from losses.

Sensitivity—The second component of vulnerability, focusing on the relative impact of losses to an entire community (for example, the percentage of a community’s workforce in a tsunami zone); for population data, it refers to differential impacts between demographic groups (for example, differences based on age of individuals or race).

Vulnerability—The attributes of a human-environmental system that increase the potential for hazard-related losses or reduced performance; characterized by the exposure, sensitivity, and resilience of a community and its assets in relation to stressors, either chronic or sudden (Turner and others, 2003).

Appendix A. North American Industry Classification System (NAICS) Codes

The following is a list of community assets that can be extracted from the infoUSA Employer Database. Numbers refer to the eight-digit code of the North American Industry Classification System (NAICS) code (U.S. Census Bureau, 2007b).

Critical Facilities	Essential Facilities

Public Order
  Police stations
    Federal: 92212002
    Police departments: 92212003
    Sheriff: 92212004
    State Police: 92212005
  Fire stations
    County Fire: 92216001
    Local Fire: 92216003
    State Fire: 92216004
  Civil Defense
    Civil Defense: 92219001
    County: 92219003
  National Security
    Federal: 92811003
    State: 92811007
Medical Services
  Hospitals: 62211002
  Outpatient care centers:
    Childbirth education: 62141003
    Pregnancy counseling: 62141005
    Clinics: 62149301
  Physician offices: 62111107
  Ambulance services: 62191002
Utilities
  Wastewater treatment:
    City: 92613001
    County: 92613002
  Water and sewage companies: 22131003
  Gas companies: 22121002
  Electric companies: 22112202
  Public works: 23731004
  Radio and TV Broadcasting: 51511203
	Gas stations: 44719005
	Banks and Credit Unions:
	  Banks: 52211002
	  Credit Unions: 52213003
	Retail Grocers: 44511003
	Courts and legal counsel
	  Federal Courts: 92211004
	  State Courts: 92211006
	  City Legal Counsel: 92213001
	  County Legal Counsel: 92213002
	  State Legal Counsel: 92213004
	Government offices:
	  City government offices: 92112006, 92113001, 92119001
	  County government offices: 92112007, 92113002, 92119002
	  State government offices: 92112008, 92113005, 92119006
	  Federal government offices: 92112009, 92119003
	  Government weather offices: 92119000
	International affairs offices: 92812003

The following is a list of community assets that can be extracted from the infoUSA Employer Database. Numbers refer to the eight-digit code of the North American Industry Classification System (NAICS) code (U.S. Census Bureau, 2007b)—Continued.

Public venues	Dependent Populations

Libraries
  City: 51912001
  Federal: 51912003
  Institutional: 51912005
  Public: 51912006
  State: 51912011
Shopping centers and malls: 53112008
Public venues:
  Museums: 71211001
  Historical Places: 71212001
  Botanical Gardens: 71213003
  Aquariums: 71219001
  Zoos: 71213006
  Parks: 71219004
  Theaters: 71111007
  Spectator Sports: 71121203, 71121204
Religious Organizations
  Christian Science: 81311005
  Church Organizations: 81311006
  Churches: 81311008
  Clergy: 81311009
  Convents and Monasteries:
  Mediation Organizations: 81311011
  Mosques: 81311015
  Religious Organizations: 81311021
  Retreat Houses: 81311023
  Spiritualists: 81311025
  Synagogues: 81311026
  Places of Worship (non-theistic): 81311031
	Hospitals
	  Hospitals: 62211002
	  Mental Health Services: 62221001
	  Psychiatric treatment facilities: 62221003
	Outpatient Care Centers
	  Childbirth education: 62141003
	  Pregnancy counseling: 62141005
	  Clinics: 62149301
	  Offices of physicians: 62111107
	  Ambulance services: 62191002
	Adult residential care
	  Adult care facilities: 62311001
	  Hospices: 62311011
	  Nursing homes: 62311016
	  Nursing home services: 62311018
	  Rest homes: 62311020
	  Retirement communities: 62331101
	  Homes – adult: 62331203
	  Senior citizens services: 62331205
	  Residential care homes: 62331206
	  Sheltered care homes: 62399000
	  Group homes: 62399007
	  Foster care: 62399013
	  Day care centers – adult: 62412002
	Child day care
	  Babysitters: 62441001
	  Childcare centers: 62441002, 62441003
	  Pre-schools: 62441005
	  Nursery schools: 62441006
	Schools
	  Religious schools: 61111004
	  Schools: 61111007
	  Schools with special academics: 61111010
	  Home schooling: 61111016
	  Colleges: 61131009
	Correctional Facilities
	  State: 92214002
	  Federal: 92214003

Appendix B. Overview of Project Database

Additional data on the distribution of assets within specific tsunami-evacuation zones and CDPs is provided in the database that accompanies this report.

Database worksheet—"By Evacuation Map"

Information on specific evacuation-zone maps (for example, the number of employees in tsunami-evacuation map 64) can be found in the "By Evacuation Map" worksheet in the project database. Rows 3 through 87 refer to specific tsunami-evacuation zone maps, rows 88 – 91 are county-level summaries, and rows 92 – 97 are descriptive statistics, including a state total, minimum value, 1st quartile, median, third quartile, and the maximum value found in the study area.

The first four columns identify the evacuation map name (A), the map number (B), the island where this zone is (C), and the county where this zone is (D). The remaining columns note the number or amount of a specific attribute in a given tsunami-evacuation zone. Land-cover attributes (columns E – H) refer to the number of cells with 30-meter resolution; however, the amount of cells can be converted to areas (km2) by multiplying by 0.0009. Residential and employee population attributes (columns I – W) refer to the total number of people, except for columns T-V which refer to the number of households. Dependent population and public venue information (columns X – AQ) refers to the number of facilities and not the number of people at each location. Hotel information includes the sum of average daily visitors (column AR) and the number of hotels (column AS). Parcel data include property value (AT), content value (AU), total value (AV), property value minus exemptions (AW), content value minus exemptions (AX) and total value minus exemptions (AY). Business information includes the number of business, employees and sales volume (columns AZ – BB). Critical and essential facilities information (columns BC – BV) refers to the number of facilities.

Database worksheets—"By CDP"

The above information summarized by tsunami-evacuation zone is also summarized by census-designated place (CDP) in a series of "By CDP" worksheets. In the numerous "By CDP" worksheets, rows 3 – 67 refer to the 65 CDP that have land in a tsunami-evacuation zone and rows 68 – 71 refer to the non-CDP land in the four counties (Maui, Kaua‘i, Hawai‘i, and Honolulu). Rows 72 – 75 are county-level summaries and rows 76 – 81 provide descriptive statistics similar to the "By Evacuation Map" worksheet.

In the "By CDP" worksheets (for example, Land Cover, Population, Economy, and Facilities), the first four columns identify the CDP name, a geographic identifier, island name, and the county name. We developed a geographic identifier for each CDP that identifies the county (for example, Ma = County of Maui, Ka = County of Kaua‘i, Ho = City and County of Honolulu, and Ha = County of Hawai‘i) and a number. We assigned numbers by starting with one community on an island and going clock-wise around an island. Sorting and graphing information by the geographic identifier allows one to graph and visualize information in a consistent fashion based on geographic location. The remaining columns in the four "By CDP worksheets" note the following for each CDP:

- The amount of an attribute located in the tsunami-evacuation zone of the CDP ("In Evacuation Zone");
- The CDP's total amount ("CDP Total"); and
- The percentage of an attribute in the tsunami-evacuation zone of a CDP ("% of CDP"), which is derived by dividing the "In Evacuation Zone" amount by the "CDP Total."

Again, land-cover data refer to the number of 30-meter cells, residential and employee data refer to the number of individuals, parcel data refer to 2006 U.S. dollars, and facility data refer to the number of facilities. Demographic data includes an additional attribute noted as "% of Total Population in Evacuation Zone." While "% of CDP" notes the percentage of a demographic category of a CDP in the hazard-prone area, "% of Total Population in Evacuation Zone" notes the percentage of residents in the evacuation zone of a CDP that are a certain demographic group. For example, a "% of CDP" value of 34 in the Hispanic or Latino population category indicates that 34 percent of the Hispanic population of a CDP is in the tsunami-evacuation zone. A "% of Total Population in Evacuation Zone" value of 34 in the Hispanic or Latino population category indicates that 34 percent of the residents in the evacuation zone are Hispanic.

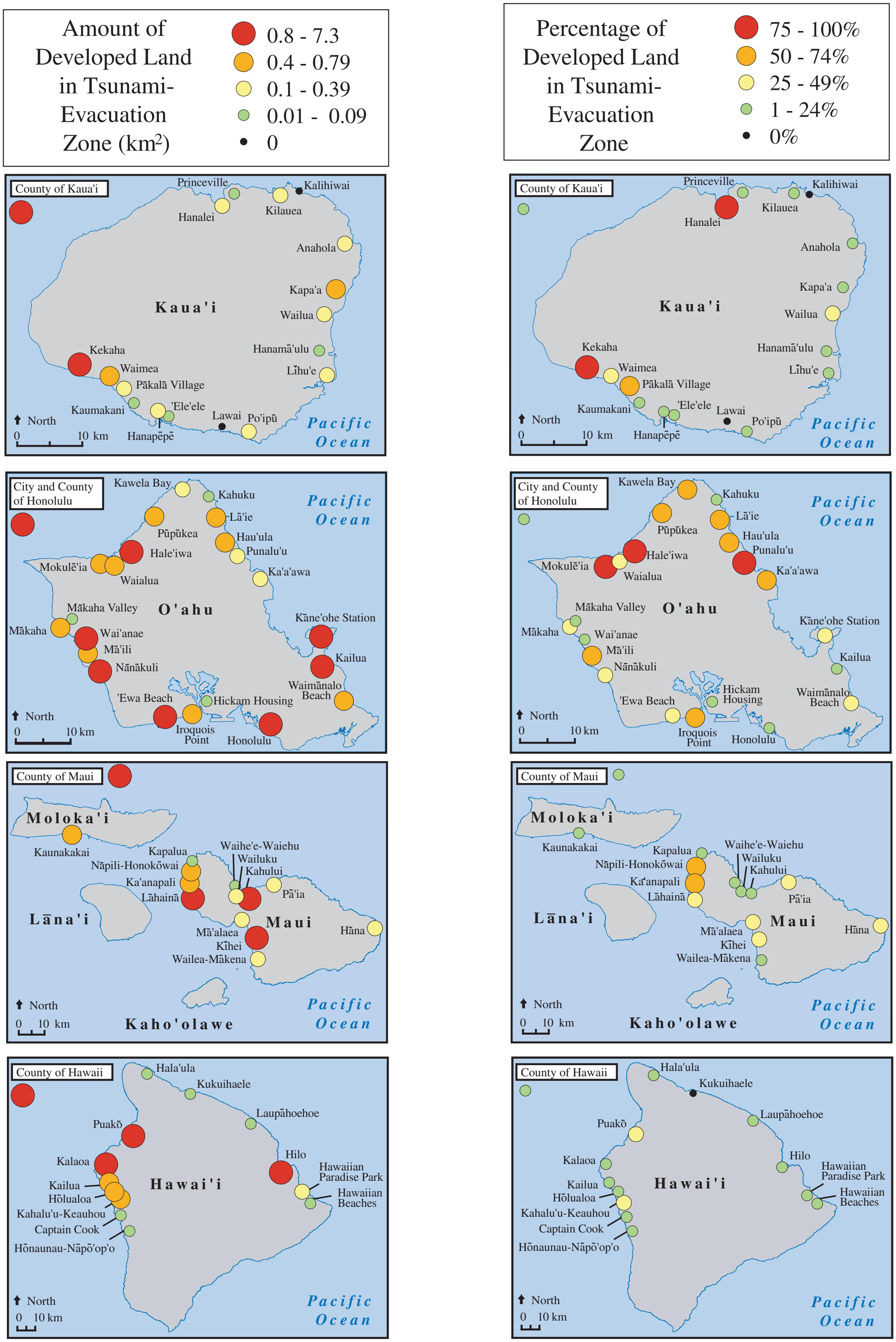
Database worksheets—"By State-Business Types"

The distribution of business types are summarized in the database worksheet "By State - Business Types." Rows in this worksheet are the 21 industry types, based on the first two digits of the North American Industry Classification System code attached to each business in the infoUSA Employer Database. Information on businesses, employees and sales volume are each sorted by business type.

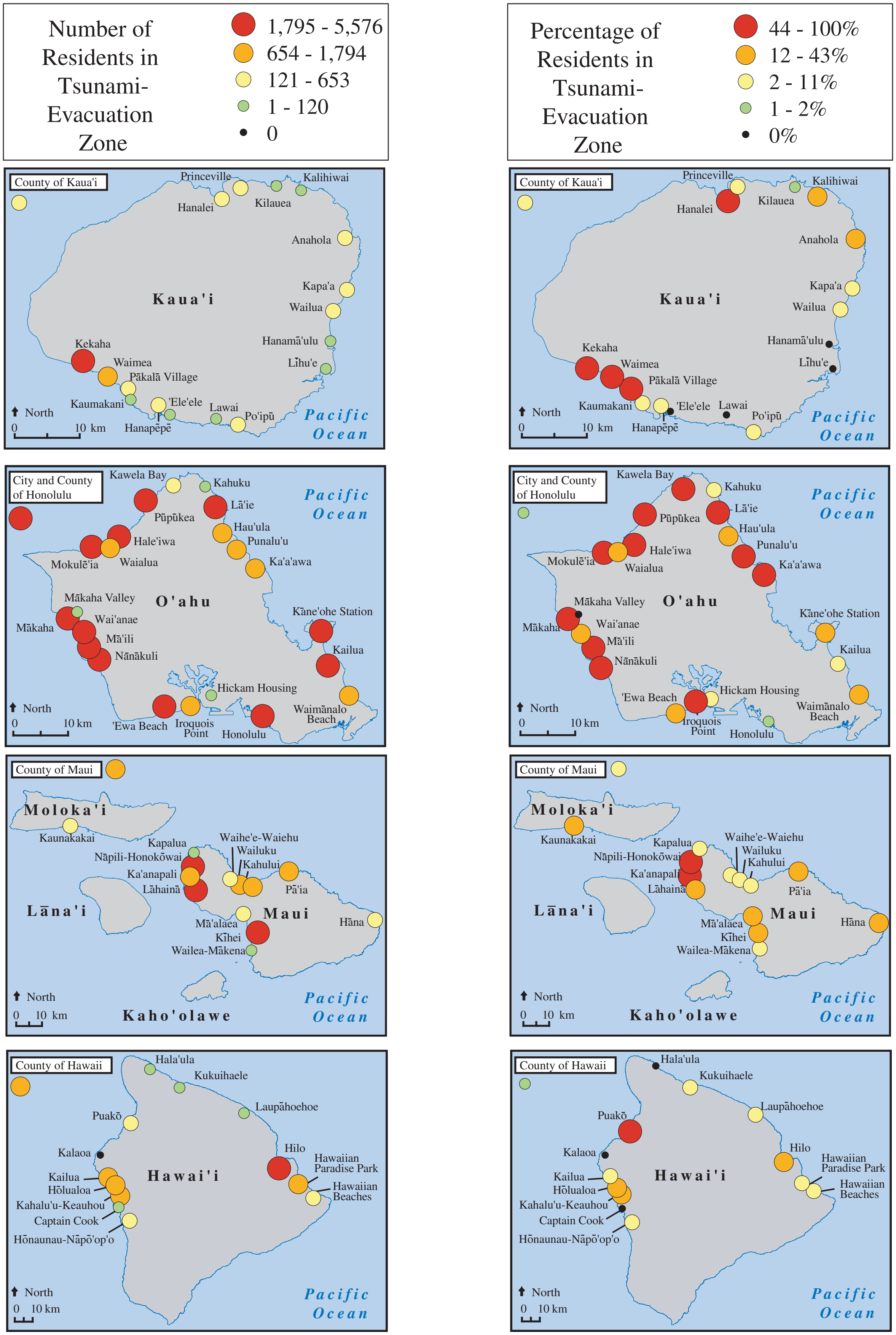
Appendix C.
Supplemental Maps of Exposure and Sensitivity Results

Some readers of this report may wish to see results in a map-based format, rather than bar graphs. However, including both types in the main body of the report would slow down the narrative and overwhelm the reader. Therefore, map-based versions of the amount and percentage of developed land (fig. 5), residents (fig. 6), employees (fig. 7), hotel average-daily-visitor (ADV) values (fig. 8) and total parcel value minus exemptions (fig. 10) are provided here. Exposure values are actual amounts, organized by quartiles. In the case of hotel average daily visitor (ADV) values, the 1st and 2nd quartiles are both zero; therefore the legend only notes the 3rd quartile (529) and the maximum. Values for community sensitivity, defined here as the percentage of a community's asset in the tsunami-evacuation zone, are percentages and organized in 25 percent increments.

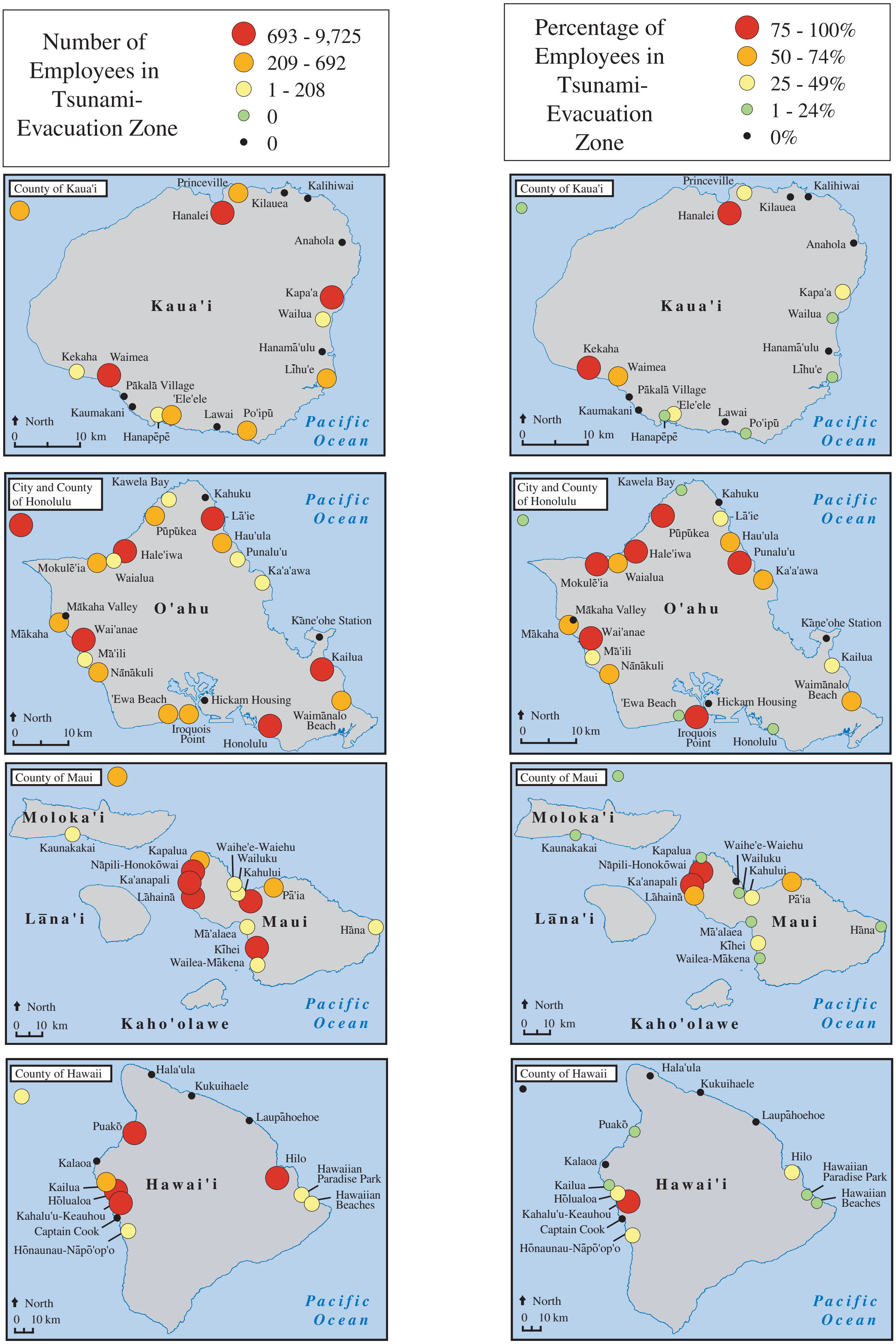
Appendix C. Continued.



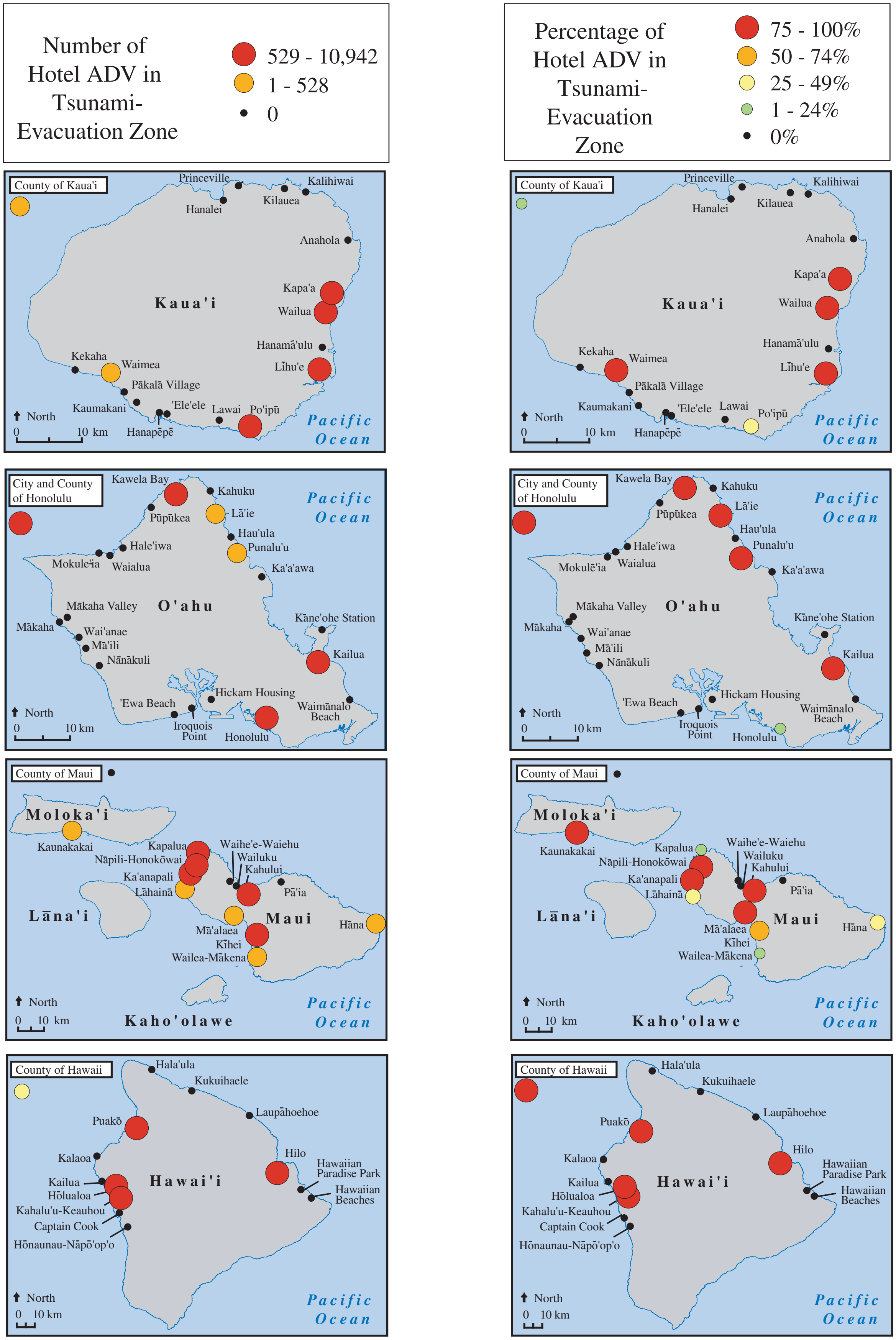
Appendix C. Continued.



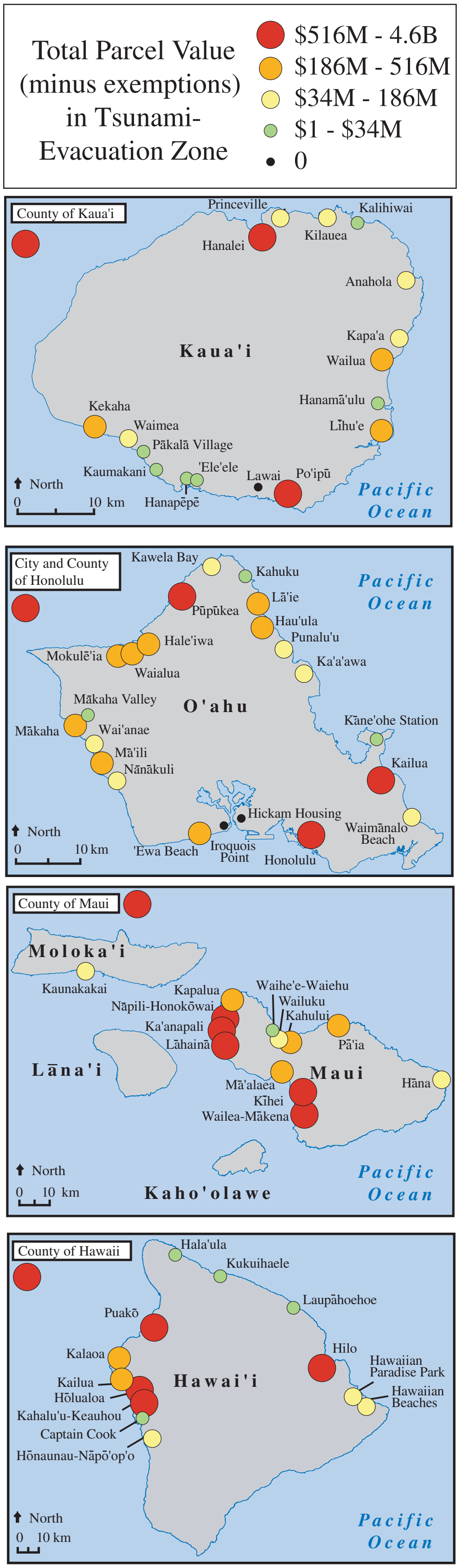
Appendix C. Continued.

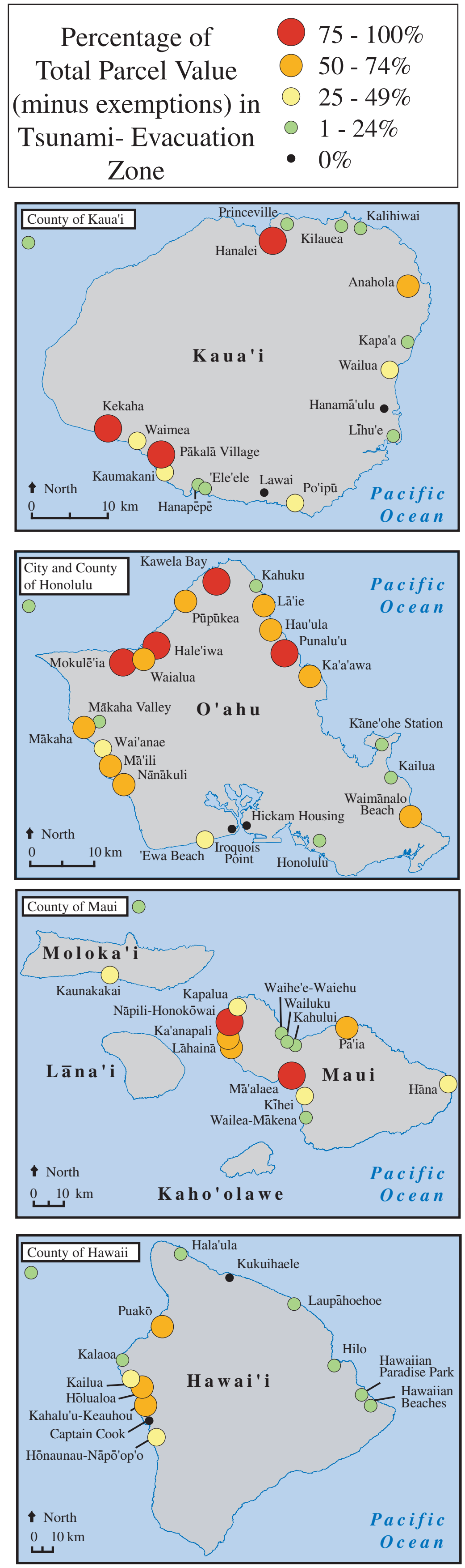


Appendix C. Continued.



Appendix C. Continued.





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