PACIFIC ISLANDS FISHERIES SCIENCE CENTER

Examining the Potential of Using Secondary Data to Better Understand Human-Reef Relationships across the Pacific

Cynthia A. Grace-McCaskey

May 2014

Administrative Report H-14-01

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CONTENTS

INTRODUCTION

Over the past 20 years, it has become increasingly clear that coral reefs are some of the most threatened ecosystems in the world. It is now generally accepted that humans impact reefs in a variety of ways, from fishing to climate change, and current research has begun to examine the intricacies of the relationships between anthropogenic factors and coral reef health (Cinner et al., 2009; Mora, 2008; Williams et al., 2008, 2011). For example, studies have focused on the relationships between artisanal fishing and key functional groups of herbivorous reef fish (Lokrantz et al., 2010), the role of fish markets in driving resource use and reef conditions (Brewer et al., 2009), and the relationship between human population size and coral disease (Aeby et al., 2011a). These studies are important because coral reefs provide critical resources to millions of people throughout the world, by providing food, jobs, and coastal protection (Cinner, 2010; Kronen et al., 2010; Wilkinson, 2002). In order for humans to continue to use the reef resources on which they depend, we must find ways to discriminate among stressors so that appropriate and effective management strategies can be developed.

One approach that has been used by researchers to examine the relationships between anthropogenic factors and coral reef health is to compare data from several islands and reefs that occur across a wide range of biological, climatic, and anthropogenic conditions. Islands suitable for these “natural experiments” are found in the Pacific Islands Region, including the Hawaiian Islands, the Line Islands, the Phoenix Islands, and several other U.S.-affiliated islands (i.e., The Commonwealth of the Northern Mariana Islands [CNMI], Guam, and American Samoa). Researchers have begun to describe the variation that exists throughout this region’s reefs in terms of fish assemblages (Friedlander and DeMartini, 2002; Stevenson et al., 2007; Williams et al., 2008, 2011), coral disease (Aeby et al., 2011a, 2011b), and overall reef community structure (Sandin et al., 2008). Several of these studies have examined the correlation between the variation in ecological components and human population or population density, using those data as proxies for an overall level of anthropogenic impact.

To move beyond using population as a proxy for anthropogenic impacts on reef ecosystems, this report examines the potential of using secondary human and social data to better understand the complexities of human-reef relationships in the Pacific Islands Region. It has also become increasingly common for researchers to develop and use a set of indicators to examine relationships between ecological and human dimensions variables. Several recent studies have shown the utility of this approach (Cinner and McClanahan, 2006; Hoffman, 2002; Turner et al., 2007), but these often involve cases in which specific socioeconomic data needs could be identified and then collected in a consistent manner across all study sites. For this study, such an approach was not possible; therefore, this report examines the utility of comparing a set of Pacific Islands using socioeconomic data from secondary (already existing) sources.

This report is organized into several sections: methods, description of the study sites, a description of how human dimensions indicators in four topic areas (population and demographics, reef fishing pressure, land and watershed alterations, and economic development and marine resource governance) could be used to make comparisons across the study sites, and conclusions (including caveats).

METHODS

In developing this report, four main aspects of humans' relationships with coral reef resources were evaluated: 1) population and demographics, 2) reef fishing pressure, 3) land and watershed alterations, and 4) economic development and marine resource governance. These aspects are generally accepted as having the potential to significantly impact the health of coral reef ecosystems. For each of these topics, a general literature review was conducted to understand how past and current research approaches the relationships between humans and reefs for each aspect. Next, a substantial effort was made to identify any and all data available on each topic across all of the study locations. These data sets were analyzed for accuracy, reliability, and comparability. Where data were found to be at least somewhat comparable for a specific aspect or indicator, they were included in the analyses, with notes provided regarding any caveats about the use of those data where necessary. Where island-scale data on a particular aspect were not found for the majority of study sites, comparative data are provided in the best manner possible; in some cases this means data are presented and comparisons are made at the island group scale (Hawai`i as a unit, CNMI as a unit, etc.), in other cases this means data can only be presented for and comparisons made between a subset of the islands or island groups. As a result, the approach used to synthesize the human dimensions data for each aspect varies. In addition to presenting the data for each aspect, each section of this report includes a description of the approach used, an explanation of how the data presented (or similar data) could be used to better understand human-reef relationships, and a discussion of the potential problems related to the use of the data currently available. This approach also allows readers to understand the variety of approaches that could be taken to analyze and compare human-reef relationships across geographies if reliable and comparable data were available.

This report is a result of a larger research project titled "Comparative Analyses of Natural and Human Influences on Coral Reef Community Structure, Diversity, and Resilience," funded by the Comparative Analysis of Marine Ecosystem Organization (CAMEO), a joint partnership between NOAA Fisheries and the National Science Foundation's Division of Ocean Sciences. The Coral Reef Ecosystem Division (CRED) of NOAA Fisheries has been monitoring the coral reef ecosystems of the U.S. Pacific islands and territories for more than 10 years though the Pacific Reef Assessment and Monitoring Program (RAMP). These methodologically consistent RAMP data allow for comparative analyses that address fundamental questions regarding the role of ecosystem organization and structure in maintaining ecosystem resilience. Further, collaboration with Scripps Institution of Oceanography's Center for Marine Biodiversity and Conservation (CMBC) allows inclusion of similar data collected during expeditions to the Line and Phoenix Islands (including U.S. Pacific Remote Island Areas and the Kiribati Line and Phoenix Islands).

Overview of Reef Locations in the Study

The sites in this report include 70 islands, atolls, and submerged banks of Hawai`i, American Samoa, the Mariana Archipelago, and the Line and Phoenix Islands (Fig. 1). They are diverse geologically, ecologically, and socially, and represent various political scales. These include a U.S. state (Hawai`i), U.S. territories (Guam, CNMI, American Samoa), a developing country (Kiribati), and the islands and atolls of the U.S. Pacific Remote Island Areas (PRIA) (Table 1). This section identifies relevant physical and social attributes contributing to the condition of coral reefs as well as the manner in which reefs and other marine resources are used and perceived by residents and visitors. This section is not intended to be an exhaustive description of these islands; for such a description, please refer to the reports and other documents identified in subsequent sections.

Hawaiian Archipelago

The Hawaiian Archipelago is about 2,960 km in length and extends across the Tropic of Cancer in the north central Pacific Ocean. The archipelago consists of eight large islands to the southeast—the main Hawaiian Islands (MHI)—and more than 120 small islands, reefs, and submerged banks to the northwest—the Northwestern Hawaiian Islands (NWHI).

Main Hawaiian Islands (MHI). -- The MHI are largely made up of populated, high, volcanic islands with non-structural reef communities, fringing reefs, and two barrier reefs (Fig. 2). The eight main islands range in age from 7 million years (Kaua`i) to less than a day old (active lava flows on the east side of the Big Island) (Gulko et al., 2002). As a result of this age range along the MHI chain, the majority of recognized reef types are present. Hawai`i's isolated position in the middle of the Pacific Ocean means the islands' coral reefs are exposed to large open ocean swells and strong trade winds that greatly impact coral reef structure. This geographic isolation also contributes to a high degree of endemism.

Coral reefs have always been important to the islands' visitors and residents, beginning with the Polynesian settlement of the islands around 1250 AD (Titcomb, 1972; Kirch, 1982). Coral reef resources provided food, medicines, and building materials for Native Hawaiians, as well as played an important role in social and cultural customs and traditions. Although humans impacted Hawaiian coral reefs beginning with early settlement through subsistence gathering of fish and invertebrates and the construction of fish ponds on reef flats, wide-scale degradation likely began 100 to 200 years ago with the settlement of Western populations. Agriculture and livestock grazing were the primary land uses on O`ahu, Maui, Moloka`i, and Lana`i, which contributed to erosion and sedimentation on nearshore reefs (Gulko et al., 2002). Dredging and the filling in of nearshore reefs for residential, commercial, and military expansion led to continued reef degradation, especially in the last 100 years. Other changes include stream channelization and increased paving of land, which has reduced sediment erosion but increased runoff.

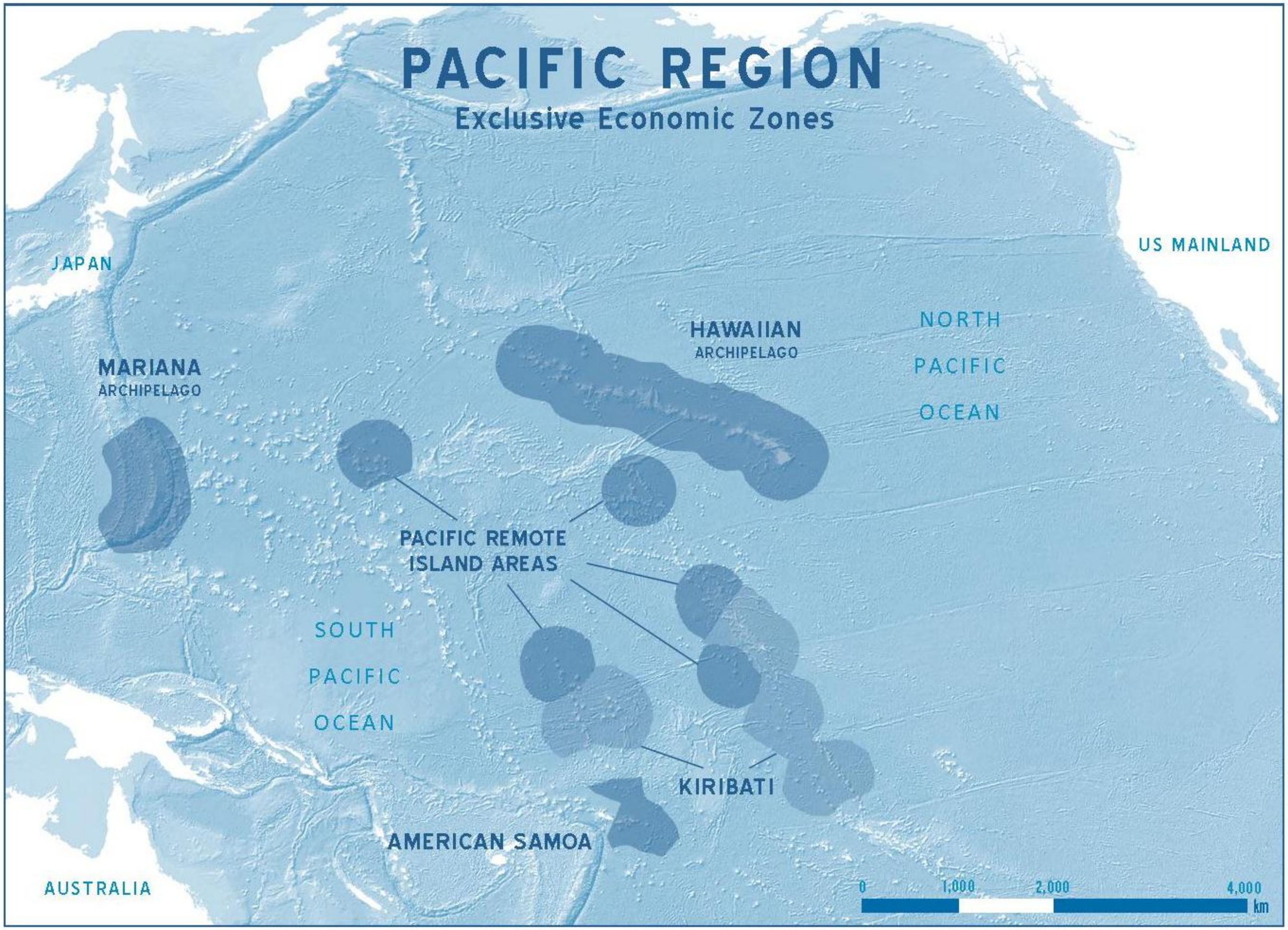

Figure 1. -- Map of the Pacific region. Shaded areas are 200 nm Exclusive Economic Zones.

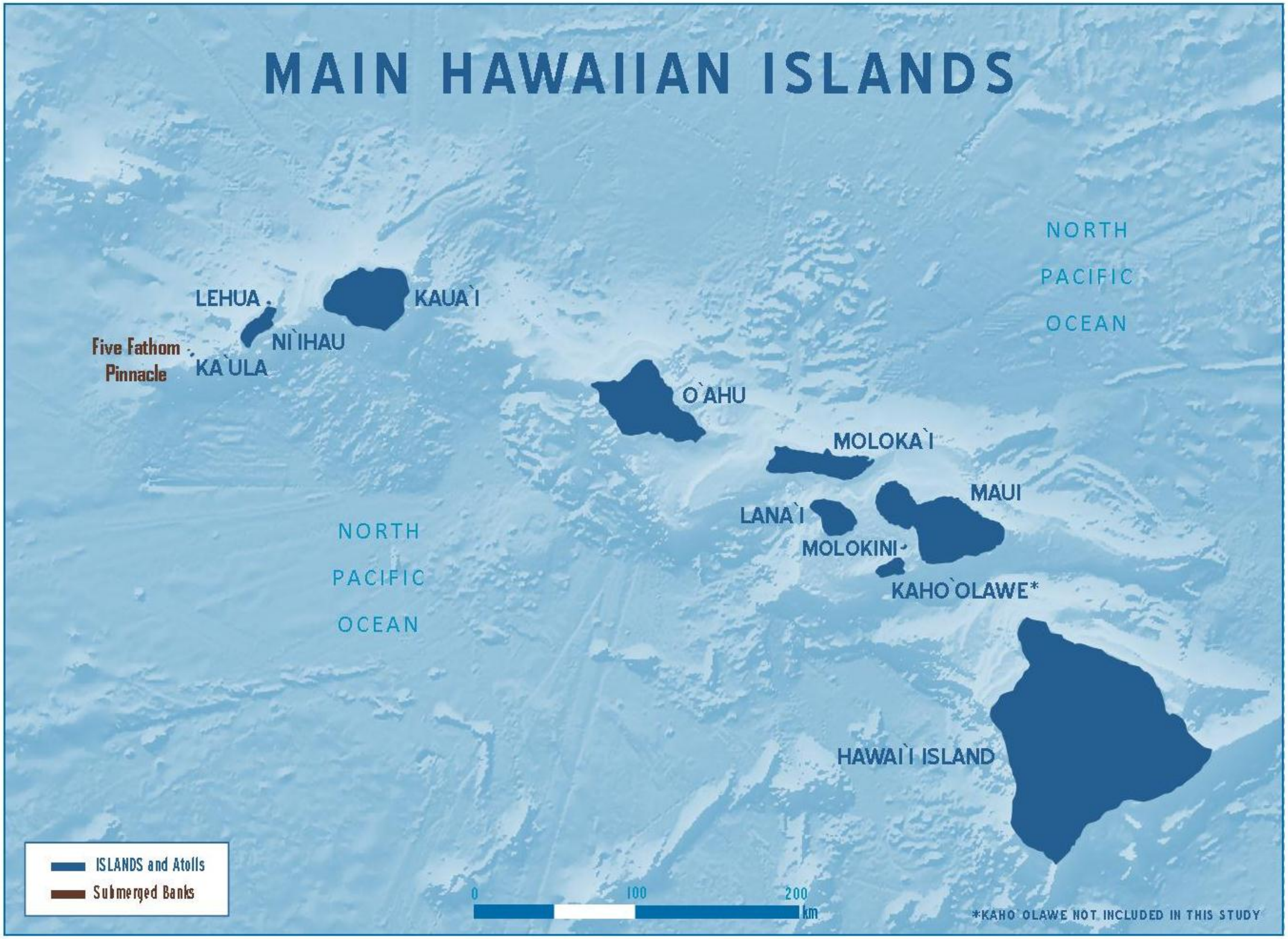

Figure 2. -- Map of the main Hawaiian Islands and location of islands, atolls, and submerged banks included in the study.

Although MHI coral reefs have suffered from degradation, they continue to be very important to the islands' residents and visitors. They provide habitat for commercial, recreational, and subsistence fishing, and produce world-renowned surfing, snorkeling, and diving locations. Of the islands' seven million annual visitors, nearly 80 percent engage in marine activities (State of Hawai`i, 2011), and coral reefs are a critical component of the islands' approximately $800 million per year marine tourism industry (Friedlander et al., 2005). Additionally, in 2002, Cesar et al. (2002) found that the average annual value of MHI coral reefs was $364 million.

Table 1. -- Basic data for the 70 islands, reefs, and atolls included in the study.

Island, Reef or Atoll	Island Group	Political Group	Population
Agrihan	Marianas	CNMI	0
Aguijan	Marianas	CNMI	0
Alamagan	Marianas	CNMI	0
Anatahan	Marianas	CNMI	0
Arakane Reef	Marianas	CNMI	NA (submerged bank)
Asuncion	Marianas	CNMI	0
Baker	Phoenix	PRIA	0
Caroline	Line	Kiribati	0
Enderbury	Phoenix	Kiribati	0
Five Fathom Pinnacle	MHI	Hawai`i	NA (submerged bank)
Flint	Line	Kiribati	0
French Frigate Shoals	NWHI	Hawai`i	0
Gardner Pinnacles	NWHI	Hawai`i	0
Guam	Marianas	Guam	159,358
Guguan	Marianas	CNMI	0
Hawai`i	MHI	Hawai`i	185,079
Howland	Phoenix	PRIA	0
Jarvis	Line	PRIA	0
Johnston Atoll	Line	PRIA	0
Kanton	Phoenix	Kiribati	41
Kaua`i	MHI	Hawai`i	66,921
Ka`ula	MHI	Hawai`i	0
Kingman Reef	Line	PRIA	0
Kiritimati	Line	Kiribati	5,115
Kure Atoll	NWHI	Hawai`i	0
Lana`i	MHI	Hawai`i	3,135
Laysan	NWHI	Hawai`i	0
Lehua	MHI	Hawai`i	0
Lisianski	NWHI	Hawai`i	0
Malden	Line	Kiribati	0
Maro Reef	NWHI	Hawai`i	0
Maug	Marianas	CNMI	0
Maui	MHI	Hawai`i	144,444
McKean	Phoenix	Kiribati	0
Midway Atoll	NWHI	PRIA	40
Moloka`i	MHI	Hawai`i	7,345
Molokini	MHI	Hawai`i	0

Note: NA = not applicable

Table 1 *continued*

Island, Reef or Atoll	Island Group	Political Group	Population
Maug	Marianas	CNMI	0
Maui	MHI	Hawai`i	144,444
McKean	Phoenix	Kiribati	0
Midway Atoll	NWHI	PRIA	40
Moloka`i	MHI	Hawai`i	7,345
Molokini	MHI	Hawai`i	0
Necker	NWHI	Hawai`i	0
Nihoa	NWHI	Hawai`i	0
Ni`ihau	MHI	Hawai`i	170
Nikumaroro	Phoenix	Kiribati	0
O`ahu	MHI	Hawai`i	953,207
Ofu & Olosega	Samoa	American Samoa	353
Orona	Phoenix	Kiribati	0
Pagan	Marianas	CNMI	0
Palmyra Atoll	Line	PRIA	20
Pathfinder Reef	Marianas	CNMI	NA (submerged bank)
Pearl & Hermes Atoll	NWHI	Hawai`i	0
Raita Bank	NWHI	Hawai`i	NA (submerged bank)
Rawaki	Phoenix	Kiribati	0
Rose	Samoa	American Samoa	0
Rota	Marianas	CNMI	2,527
Saipan	Marianas	CNMI	48,220
Santa Rosa Reef	Marianas	Guam	NA (submerged bank)
Sarigan	Marianas	CNMI	0
South Bank	Samoa	American Samoa	NA (submerged bank)
Starbuck	Line	Kiribati	0
Stingray Shoals	Marianas	CNMI	NA (submerged bank)
Supply Reef	Marianas	CNMI	NA (submerged bank)
Swains	Samoa	American Samoa	17
Tabuaeran	Line	Kiribati	2,539
Tatsumi Reef	Marianas	CNMI	NA (submerged bank)
Ta`u	Samoa	American Samoa	790
Teraina	Line	Kiribati	1,155
Tinian	Marianas	CNMI	3,136
Tutuila	Samoa	American Samoa	54,359
Uracas	Marianas	CNMI	0
Vostok	Line	Kiribati	0
Wake Atoll	Marshall Islands	PRIA	135
Zealandia Bank	Marianas	CNMI	NA (submerged bank)

Note: NA = not applicable

Northwestern Hawaiian Islands (NWHI). -- The NWHI extend more than 2,000 km to the northwest of Kaua`i, and represent the older portion of the Hawaiian Archipelago (Fig. 3). Most of the islands, reefs, and atolls are currently uninhabited, although Midway, Kure, and French Frigate Shoals were all occupied for extended periods of time throughout the 1900s; Kure and French Frigate Shoals held U.S. Coast Guard Long-Range Aids to Navigation (LORAN) stations, and Midway Atoll was occupied by military populations throughout World War II, and the Korean, Vietnam, and Cold Wars. There continues to be a small, semi-permanent Fish and Wildlife Service (FWS) field camp on Laysan, and a small FWS staff (about 40 people) currently inhabit Midway (CIA, 2013; Papahānaumokuākea Marine National Monument, 2008). The NWHI have always been honored as a deeply spiritual location by Native Hawaiians, and the presence of many *wahi kupuna* (sacred sites) on Nihoa and Necker Island are evidence of this.

In 2006, President George W. Bush designated the NWHI as a Marine National Monument, and it was renamed Papahānaumokuākea Marine National Monument in 2007 in reflection of the area's importance to Native Hawaiians. Entry to the Monument is by permit only.

The isolation and lack of inhabitants in the NWHI contributes to a relatively healthy coral reef ecosystem and a high level of endemism. Unique to the NWHI ecosystem is the abundance and dominance of large apex predators, such as sharks and jacks, which have been depleted in most other reef ecosystems throughout the world (Friedlander and DeMartini, 2002; Friedlander et al., 2008a). Issues of concern for NWHI coral reefs include the large amount of derelict fishing gear and other marine debris that accumulate in the NWHI, coral disease, ocean acidification, sea level rise, and bleaching associated with climate change (Friedlander et al., 2008a).

Mariana Archipelago

The Mariana Archipelago is about 890 km long, and is made up of 15 islands and many banks. The islands and reefs of the archipelago can be divided into 3 geologic groups: 1) several offshore banks and submarine volcanoes located on the West Mariana Ridge, including Stingray Shoals, Pathfinder Reef, and Arakane Reef; 2) the younger, volcanic northern islands on the Mariana Arc, including Anatahan, Sarigan, Guguan, Alamagan, Pagan, Agrihan, Asuncion, Maug, and Uracas; and 3) the older, southern islands on the Mariana Arc, including Guam, Rota, Aguijan, Tinian, and Saipan (PIFSC, 2010).

Commonwealth of the Northern Mariana Islands (CNMI). -- The CNMI is a commonwealth of the United States, consisting of the islands in the Mariana Archipelago stretching from Rota in the south to Uracas in the north (Fig. 4). The southern islands of Saipan, Tinian, Aguijan, and Rota are uplifted limestone, while the northern islands are volcanic. Active volcanoes exist on Anatahan, Pagan, and Agrihan. The oldest and most complex reefs in the CNMI are located along the western sides of the southern islands of Rota, Tinian, and Saipan. The 2010 U.S. Census indicated that all of the CNMI's 53,883 residents live on these three islands, although small settlements have existed at various times throughout history on the northern islands such as Agrihan and Pagan.

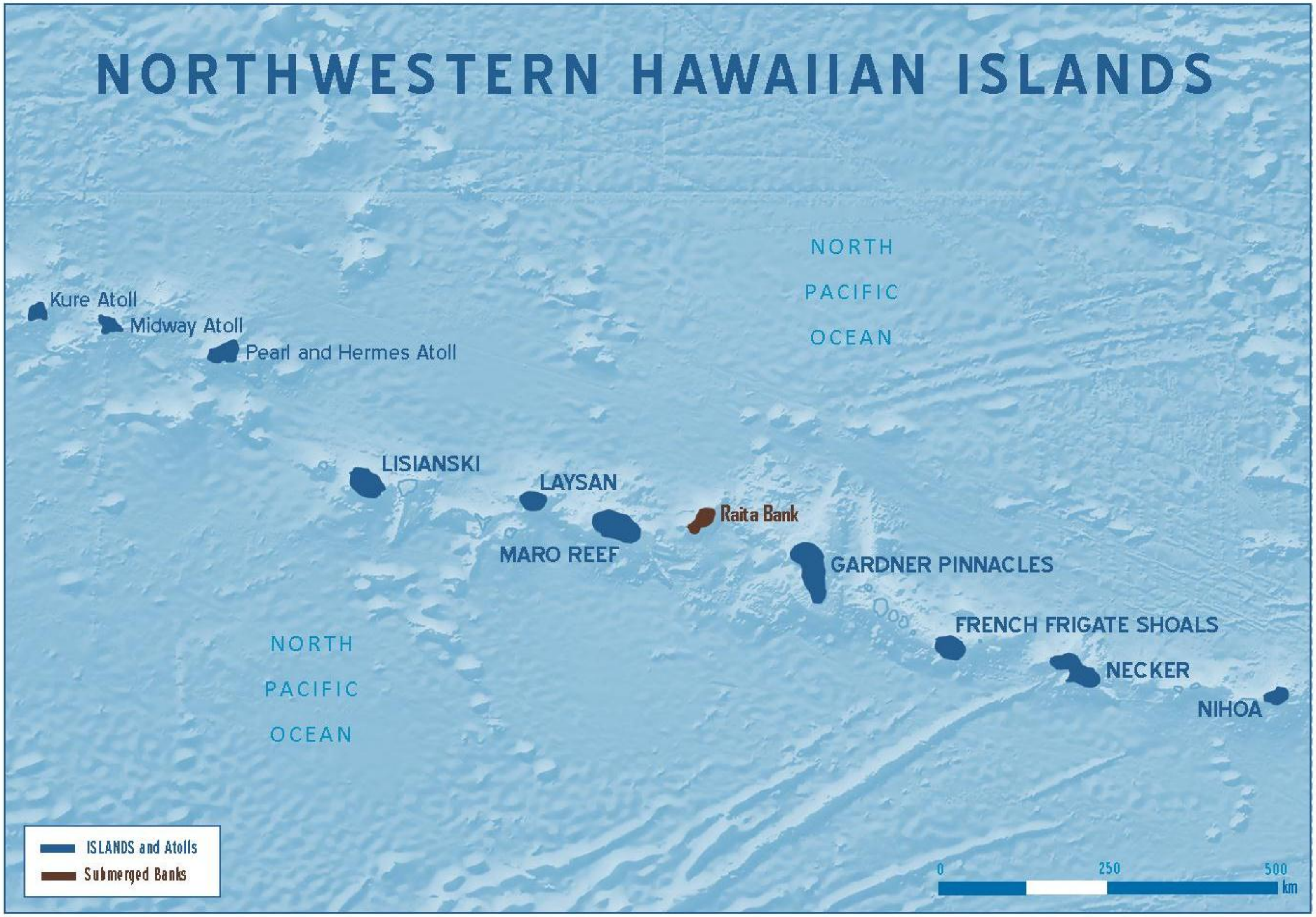

Figure 3. -- Map of the Northwestern Hawaiian Islands and location of islands, atolls, and submerged banks included in the study.

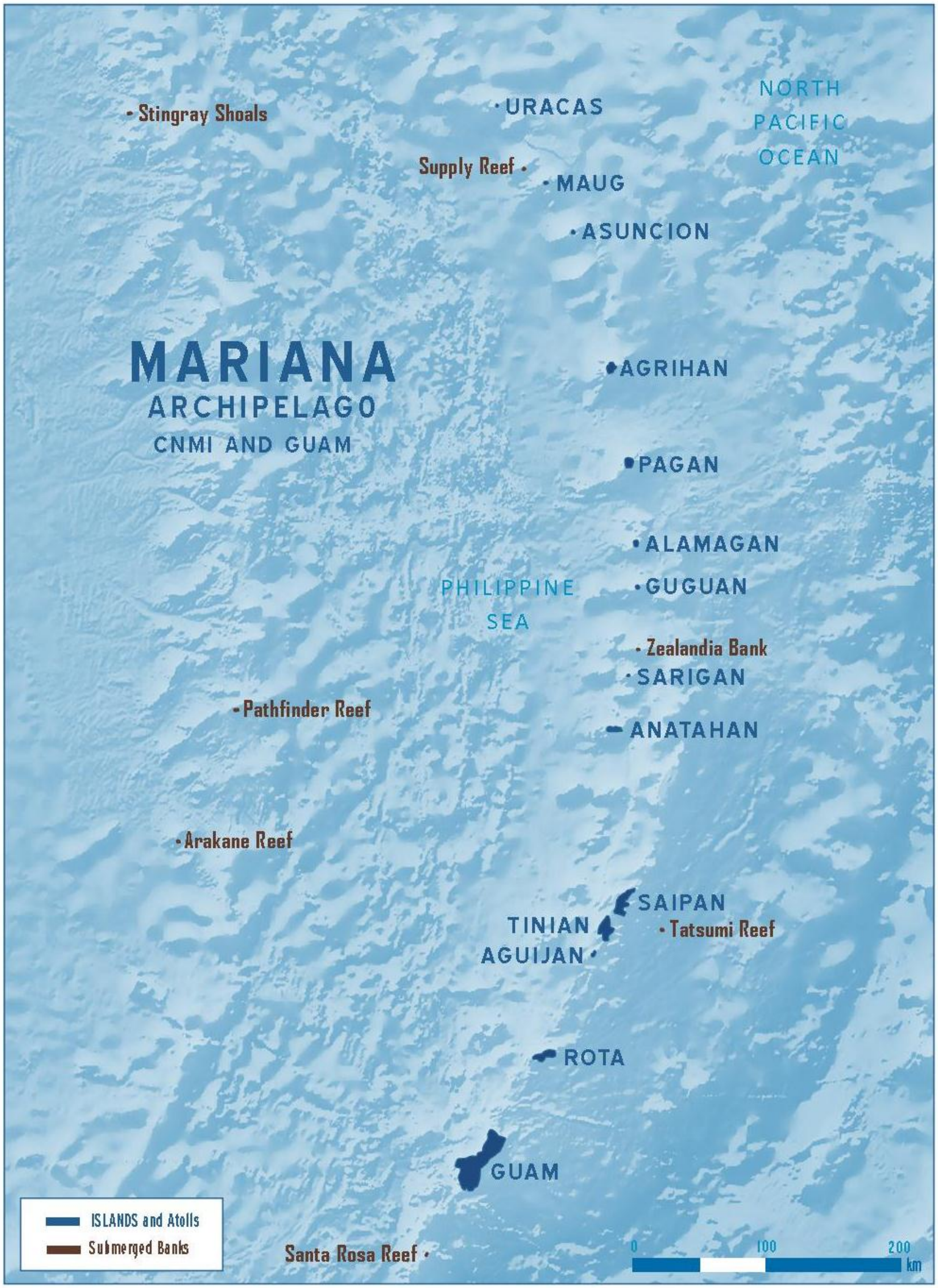

Figure 4. -- Map of the Mariana Archipelago, including the Commonwealth of the Northern Mariana Islands and Guam, and location of islands, atolls and submerged banks included in the study.

The first people arrived in the Marianas around 3,500 years ago (ancestors of the indigenous Chamorros), and the Spanish were the first Europeans to visit the present-day CNMI in the mid-1500s. Many of the islands have been ruled by several different countries leading up to present day, including Spain, Germany, and Japan, who occupied Saipan until World War II, when it was captured by the United States. After World War II, the islands were administered by the United States as part of the Trust Territory of the Pacific Islands, and in 1976 the islands separated from the Trust Territory and became a U.S. Commonwealth (Allen and Amesbury, 2012).

Beginning in the 1980s, the CNMI experienced rapid population growth, spurred on by the development of the garment and tourism industries. From 1980 to 2000, the population of Saipan increased fourfold, with the majority of the new residents being migrants from Asia looking for work. In 1995, these two industries accounted for about 80 percent of all employment in the CNMI, and in 1999, they accounted for about 85 percent of the CNMI's total economic activity and 96 percent of its exports (Allen and Amesbury, 2012). The success of the CNMI garment factories was impaired, however, when China entered the World Trade Organization in 2001 and gained access to American markets in 2005. The CNMI factories were unable to compete with China's very low wage rates, and by 2008 only 3 of the 34 factories that were operating in 2000 remained open (Malcolm D. McPhee & Associates and Conway, 2008). The closure of the factories, along with the decline of tourist arrivals due to a variety of factors including the worldwide economic recession, led to a large retraction in the CNMI economy and ultimately the out-migration of 12,388 people since 2005 (CNMI Central Statistics Division, 2008).

The development of the southern islands means that most of the human impacts to the marine environment, such as point and nonpoint source pollution, are concentrated there. In addition, impacts from climate change, tropical storms and cyclones, and reef fishing are of particular concern for the CNMI reefs. Despite these challenges, coral reef ecosystems continue to be important economically, with an estimated value of $61 million (Saipan only), 70 percent of which is accounted for by tourism (van Beukering et al., 2006).

In 2009, the 3 northernmost islands—Uracas, Maug, and Asuncion— and the waters surrounding them out to 50 nautical miles were designated part of the Marianas Trench Marine National Monument by presidential proclamation. Commercial fishing is prohibited in the Monument, and regulations are currently being created to manage other types of fishing and access.

Guam. -- Guam is the southernmost island in the Mariana Archipelago (Fig. 4), and became a U.S. territory in 1950. It is the largest and most heavily populated island in Micronesia. It is a volcanic island, and the northern part of the island is relatively flat and comprised of uplifted limestone, while the southern half has more topographic relief. A variety of reef types are represented on Guam, including fringing reefs, patch reefs, submerged reefs, offshore banks, and barrier reefs. Fringing reefs are the predominant reef type, and they surround much of the island. More than 5,100 marine species have been found in Guam's coastal waters, including more than 1,000 nearshore fish species and more than 300 scleractinian coral species (Paulay, 2003; Porter et al. 2005). Additionally, Guam is close to the Indo-Pacific center of coral reef biodiversity and as such, has more marine species richness than most other U.S. jurisdictions.

As with the other islands in this study, Guam's reef resources have always been utilized by the island's residents for food and cultural purposes. The first inhabitants of Guam, the Chamorros, are believed to have migrated from Southeast Asia around 2000 B.C. (Amesbury, 2006). The Spanish were the first Europeans to visit Guam, but the island was not colonized until 1668. Following the Spanish-American War in 1898, the U.S. Navy took control of Guam, until it was occupied by Japan from 1941 to 1944. Shortly after the end of World War II, Guam became an unincorporated, organized U.S. territory in 1950.

Guam's coral reefs are critical to the island's important tourism industry. In 2010, nearly 1.2 million people visited Guam, many of them attracted by reef-related activities, such as snorkeling and scuba diving. A recent study estimated that Guam's coral reef resources are valued at close to $127 million per year (van Beukering et al., 2007). The U.S. military has had a presence on Guam since 1898, and continues to be an important contributor to the island's economy. The number of active military and their dependents living in Guam has fluctuated over the years, and in 2010 this group made up about 8 percent of Guam's resident population. Plans are currently in place to again increase the number of military personnel in Guam (an estimated 8,000 active duty personnel plus 9,000 support personnel and dependents transferred from Okinawa) over the next few years, though final plans are still being negotiated. The effects of this influx are expected to be not just economic, but also social and environmental (Allen and Amesbury, 2012).

The health of Guam's coral reefs varies around the island, depending on a variety of environmental and social factors, such as geology, coastal development, and natural events such as tropical storms and earthquakes. Climate change, overfishing, and coastal pollution are other issues of concern for Guam's coral reefs.

Samoa Islands

The Samoa Islands are made up of high volcanic islands and low-lying atolls that have narrow reef flats and steep offshore banks. American Samoa is a U.S. territory made up of the volcanic islands of Tutuila, Ofu, Olosega, and Ta`u, and the much older and geologically unrelated atolls of Swains and Rose. The other two large volcanic islands in the island group, Upolu and Savai`i, belong to the Independent State of Samoa (Samoa). Only the islands of American Samoa are included in this study.

American Samoa. -- American Samoa is located about 4,200 km south of Hawai`i, and is the southernmost of all U.S. territories (Fig. 5). Tutuila is the largest and most populated island, with 98% of the territory's total population residing there. The Manu`a Islands (Ofu, Olosega, and Ta`u collectively) have much smaller, more subsistence-based populations, while Swains had a population of only 17 people according to the 2010 U.S. Census. Rose Atoll was established as a National Wildlife Refuge in 1973 and in 2009 became Rose Atoll Marine National Monument. This designation restricted commercial fishing and other activities inside the Monument.

Figure 5. -- Map of American Samoa and location of islands, atolls, and submerged banks included in the study.

The Samoa Islands were first settled by Polynesian explorers around 1000 B.C. and first explored by Europeans in the 18th century, although the main Western influences on Samoans at the time were limited to missionaries and traders from ships. The United States took possession of the American Samoa islands in 1899, and the island group eventually became an unincorporated territory. American Samoa experienced rapid population growth between 1980 and 2006, with the population more than doubling from 32,297 people to 66,900 people. This rapid growth was due in part to the development of two major tuna canneries in Tutuila and their efforts to recruit workers from Samoa and other countries. The recent closure of the Chicken of the Sea cannery in 2009 no doubt contributed to the decline in population to 55,519 in 2010, as reported by the U.S. Census. The canneries, along with the American Samoa government, continue to be the territory's biggest providers of employment, as well as account for the majority of American Samoa's economic base (Levine and Allen, 2009).

Coral reefs in American Samoa support a high diversity of Indo-Pacific corals (more than 200 species), fishes (approximately 890 species), and numerous invertebrates. These corals have shown a great deal of resilience in the past several decades, having been exposed to six cyclones, a major crown-of-thorns starfish outbreak in 1978, and several major bleaching events (Craig et al., 2005). Sedimentation associated with coastal development is a major issue for coral reef ecosystems, especially on Tutuila which has steep mountain slopes close to the coastlines and heavy rainfall. Point and non-point source pollution are also primary issues of concern for American Samoa's reefs. In particular, Pago Pago Harbor is highly polluted with contaminated sediments and fish processing wastes, which contribute to high bacterial levels that peak during and after heavy rains. Sources of bacterial contamination include piggeries, septic tanks, sewage, and animal wastes (Fenner et al., 2008).

Compared with many of the other island areas in this study, there is relatively little tourism in American Samoa. There are only two flights per week between Honolulu and Pago Pago, though flights are more frequent between nearby Samoa and Pago Pago. As a result, the value of American Samoa's coral reefs is estimated to be somewhat lower than the other island areas, at approximately $5 million per year in 2004 (Spurgeon et al., 2004).

Pacific Remote Island Areas (PRIA)

The PRIA are a set of isolated U.S. sovereign islands and atolls not within the jurisdiction of any U.S. state or territory. These include Howland, Baker, and Jarvis Islands; Johnston, Palmyra, and Wake Atolls; and Kingman Reef (Fig. 6). (Midway Atoll is also considered part of the PRIA, but is included in this report in the section about the NWHI.) All are single reef ecosystems that straddle the equator in the central Pacific: Johnston Atoll, Palmyra Atoll, and Kingman Reef are the three northernmost U.S. Line Islands; Wake Atoll is the northernmost of the Marshall Islands; Jarvis Island is in the central U.S. Line Islands; Howland Island and Baker Island are the two northernmost U.S. Phoenix Islands (Brainard et al., 2005).

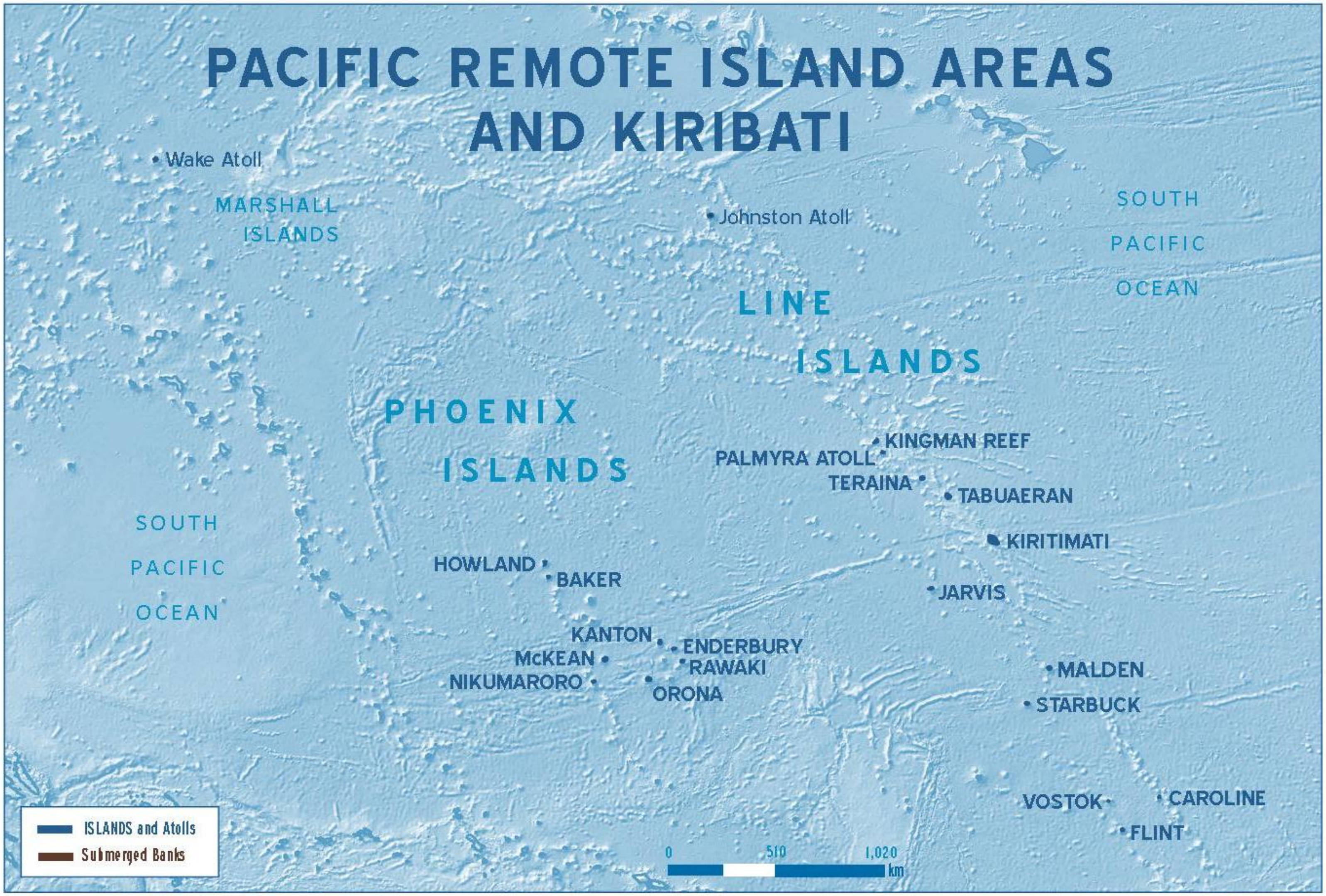

Figure 6. -- Map of the Pacific Remote Island Areas and the Kiribati islands of the Line and Phoenix Islands, and location of islands, atolls, and submerged banks included in the study.

All of the PRIA were uninhabited when first visited by Westerners over the past 200 years, but Polynesians and Micronesians likely visited all of the islands periodically for centuries. Most of the islands were claimed by the United States via the Guano Act of 1856, but the extent of guano harvesting varied. Inhospitable conditions, such as insufficient groundwater and rainfall, contributed to the lack of long-term settlement on the PRIA, aside from their use as important military bases. Most of the PRIA were modified during the World War II era, including the construction of military bases at Johnston, Palmyra, Wake, and Baker. All of the PRIA except Wake became National Wildlife Refuges between 1924 and 2001, and in 2009 they all became part of the Pacific Remote Islands Marine National Monument, managed principally by the Department of the Interior. Wake is the only one with a significant population (about 135 people, primarily contract workers who run the air force base) and its lands are still managed by the military. The Nature Conservancy has a small research station on Palmyra with a population of around 20 (Hansen, 2011; Sandin et al., 2008).

Because the PRIA are spread out over a large remote area in the central Pacific, they are influenced by varying oceanographic and climatic conditions. The PRIA represent some of the healthiest reef ecosystems anywhere in the world, with high biodiversity, coral cover and reef fish biomass, and predator-dominated systems (Friedlander et al., 2008b). Because most of the islands have been uninhabited for several years and are located far from areas of high human population, they do not suffer from the constant threat of coastal development, pollution, and fishing. For this reason, coral reef scientists feel these reefs are important to protect so that climate change-related effects, such as coral bleaching and ocean acidification, can be studied in the absence of large-scale anthropogenic impacts. However, the reefs at Johnston, Palmyra, Wake, and Baker are experiencing residual impacts from military use, including effects from dredging and filling to build aircraft runways and other installations, and effects from long-term storage of chemical and radioactive waste (Miller et al., 2008).

Kiribati Islands

The Republic of Kiribati consists of 32 atolls and 1 volcanic island in 3 main island groups in the Pacific—the Gilbert Islands, Phoenix Islands, and Line Islands. Although Kiribati has a total land area of only 810 km^2, its surrounding exclusive economic zone (EEZ) is about 3.5 million km^2 and includes some of the most productive tuna fishing grounds in the Pacific.

In 2005, the total population of Kiribati was 92,533, although 90 percent of the population resided in the Gilbert Island Group, which is not included in this study. (As mentioned earlier, the Kiribati islands included in this study are only those in the Line and Phoenix Islands for which CMBC has collected coral reef monitoring data). Of the 14 Kiribati islands included in the study (Fig. 6), only 4 are inhabited: Kanton, Kiritimati (also called Christmas Island), Tabuaeran (also called Fanning Island), and Teraina. Of these, Kiritimati has the largest population (5,115 people in 2005) and is the focus of the Kiribati Government's efforts to relocate residents from the overpopulated Gilbert Islands to the Line Islands. As a result, the population of Kiritimati increased by about 50 percent between 2000 and 2005 (Kiribati National Statistics Office, 2007). All of the Kiribati islands in this study are low-lying coral atolls, rising little more than 4 or 5 m above sea level, and surrounded by fringing or barrier coral reefs. Kiritimati is the world's largest atoll, and makes up almost half the total land area of Kiribati (Scott, 1993).

The Line and Phoenix Islands were uninhabited when first visited by Europeans in the 1600s, although Polynesians and Micronesians likely visited and explored the islands for years prior. Interest in the islands (along with the Gilbert Islands) increased in the 1800s, as traders visiting the islands exchanged a variety of goods for coconut oil and copra. The Gilbert and Ellice Islands (now Tuvalu) became a British protectorate in 1892, and by 1937 these islands, along with most of the Line and Phoenix Islands, became a British colony (Macdonald, 2001). Several of the islands, including Tarawa and Kiritimati, were occupied by the Japanese or the Allies during World War II, and nuclear weapons testing occurred on and near Kiritimati in the 1950s and 1960s. Britain also began expanding self-government during this time, and the Ellice Islands separated from the colony in 1975 to form Tuvalu. In 1979, the Gilbert, Phoenix, and Line Islands became the Republic of Kiribati.

In Kiribati as a whole, more than 95 percent of the population are native I-Kiribati, and this situation holds true for each of the 4 inhabited islands included in this study as well (Kiribati National Statistics Office, 2007). As such, many of the culture's traditional values continue to play an integral role in everyday life, such as the importance of equality among all people and a collectivist approach to economics and governance. Despite the efforts to increase development of Kiritimati, it and the other 3 Kiribati islands in the study support primarily traditional, subsistence livelihoods. As a whole, Kiribati has few resources on which to base an economy, and a large percentage (more than 40 percent) of the government's revenue typically comes from access fees paid by foreign fleets to fish for tuna in Kiribati's exclusive economic zone (EEZ) (Gillett, 2009; 2010). Kiritimati also hosts a small tourism industry.

Research regarding coral reef health in the Kiribati islands in this study has not been as extensive as in the other island areas included here. However, studies comparing several aspects of coral reef ecosystems of the populated Tabuaeran and Kiritimati with those of the unpopulated nearby Kingman Reef and Palmyra Atoll suggest that changes in fish assemblages and coral cover at Kiritimati and Tabuaeran are linked with a variety of environmental and anthropogenic factors, including bleaching, fishing, and pollution (Sandin et al., 2008). Moreover, because the islands have very little elevation above 5 meters, the effects of global climate change such as sea level rise are not only environmental concerns, but threaten the existence of many island communities (Awira et al., 2008). Additionally, although the Kiribati government has recognized current issues regarding marine environment degradation (such as overfishing in the Kiritimati Lagoon), the prevalence of poor health conditions and lack of sanitation facilities are of greater concern.

In 2006, Kiribati designated the Phoenix Islands Protected Area (PIPA), now one of the largest marine protected areas (MPA) in the world. PIPA includes all eight islands and atolls of the Phoenix Islands (including the six Phoenix Islands in this study), and is managed by the Kiribati Government in partnership with the New England Aquarium and Conservation International.

POPULATION AND DEMOGRAPHICS

This section describes and compares the islands in the study in terms of population and demographic data. As mentioned in the introduction, population or population density is often used as a proxy for the overall level of anthropogenic impact on coral reef conditions in studies examining human-reef relationships. In addition to comparing the islands in the study in terms of traditionally-used population data, the analysis also presents alternative types of population data (e.g., percent of population change and visitor population) and demographic data (e.g., ethnicity and nativity), and describes how these data might be used to better understand human-reef relationships.

Population

This set of indicators examines the relationships among islands in terms of population. Of the 70 islands, atolls, and reefs in the study, 23 are (or were recently) populated and so are included in this section. Table 2 provides data for these islands in terms of their most recent population estimates (2010 for the U.S.-affiliated islands, 2005 for the Kiribati islands) as well as their change in population between 2000 and the most recent population estimate.

Not surprisingly, O`ahu has the highest population in both 2000 and 2010. In 2010, O`ahu's population was more than 760,000 greater than the next most populated island of Hawai`i. Additionally, the 7 most populated islands in 2000 (Fig. 7) remained so in 2010, with minimal change in rank ordering. Five of these 7 islands have seen an increase in population since 2000, while 1 (Tutuila) has seen a slight decrease, and 1 (Saipan) has seen almost a 25 percent decrease in population.

In addition to reflecting natural population growth, in some cases, these population increases are connected with the movement of people from more remote, less-populated islands to the more populated economic centers of the U.S. territories (Fig. 8). For example, the population of the remote islands of Ofu and Olosega in American Samoa has decreased by more than 30 percent since 2000. Interviews with American Samoan residents indicate that increasing numbers of teenagers and young adults leave these outer islands to move to Tutuila in search of better schooling and employment opportunities. Similar decreasing trends are seen in Rota and Tinian in the CNMI, which have lost 23 percent and 11.4 percent of their populations since 2000, respectively.

Table 2. -- Most recent population estimates of inhabited islands (2010 for U.S.-affiliated islands, 2005 for Kiribati islands), population in 2000, and rate of population change.

	Most Recent Population	Population in 2000	Percent Population Change since 2000
Johnston	[c] 0	[g] 970	-100.0
Swains	[a] 17	[e] 37	-54.1
Palmyra	[c] 20	[g] 20	0.0
Midway	[c] 40	[g] 150	-73.3
Kanton	[b] 41	[f] 61	-32.8
Wake	[d] 135	[g] 124	8.9
Ni`ihau	[a] 170	[e] 160	6.3
Ofu & Olosega	[a] 353	[e] 505	-30.1
Ta`u	[a] 790	[e] 873	-9.5
Teraina	[b] 1,155	[f] 1,087	6.3
Rota	[a] 2,527	[e] 3,283	-23.0
Tabuaeran	[b] 2,539	[f] 1,757	44.5
Lana`i	[a] 3,135	[e] 3,193	-1.8
Tinian	[a] 3,136	[e] 3,540	-11.4
Kiritimati	[b] 5,115	[f] 3,431	49.1
Moloka`i	[a] 7,345	[e] 7,404	-0.8
Saipan	[a] 48,220	[e] 62,392	-22.7
Tutuila	[a] 54,359	[e] 55,876	-2.7
Kaua`i	[a] 66,921	[e] 58,303	14.8
Maui	[a] 144,444	[e] 117,644	22.8
Guam	[a] 159,358	[e] 154,805	2.9
Hawai`i	[a] 185,079	[e] 148,677	24.5
O`ahu	[a] 953,207	[e] 876,156	8.8

Notes:
[a] 2010 U.S. Census data from U.S. Census Bureau (2012)
[b] 2005 Kiribati Census data from Kiribati National Statistics Office (2007)
[c] CIA (2012)
[d] Hansen (2011)
[e] 2000 U.S. Census data from U.S. Census Bureau (2012)
[f] 2000 Kiribati Census data from Kiribati National Statistics Office (2007)
[g] CIA (2001)

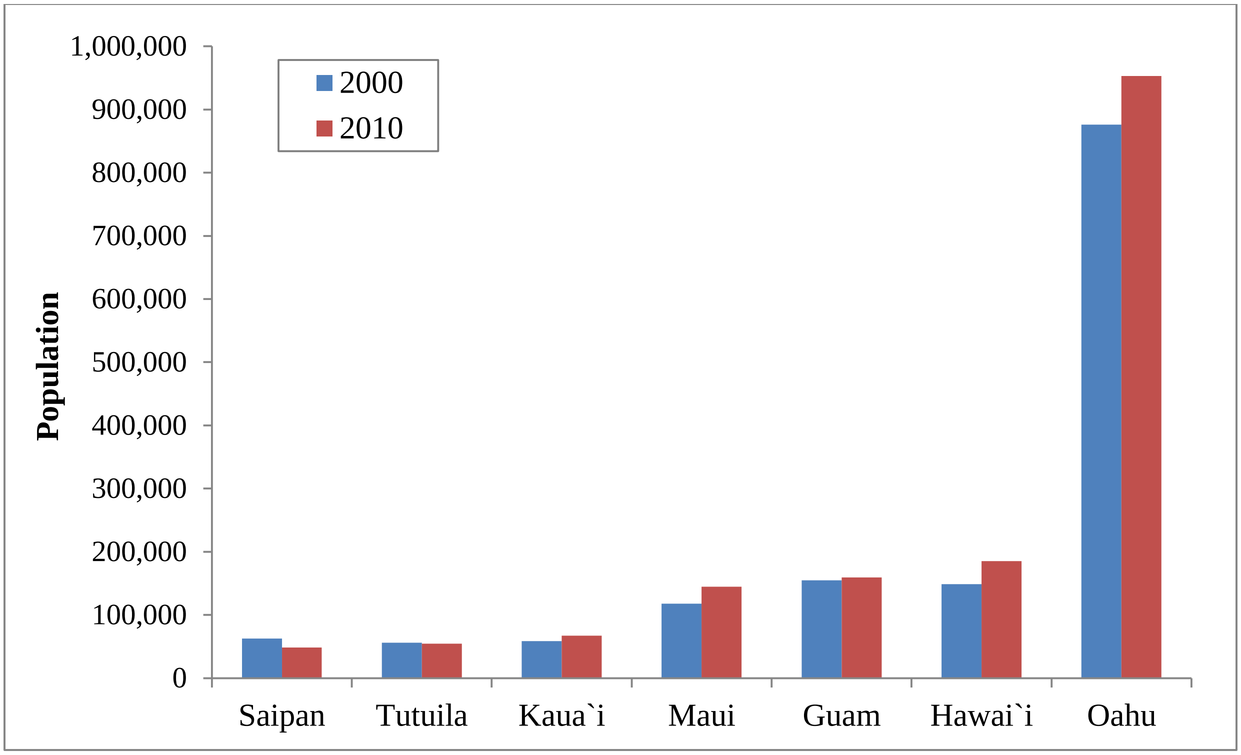

Figure 7. -- Population in 2010 and 2000 for the most populated islands in the study.

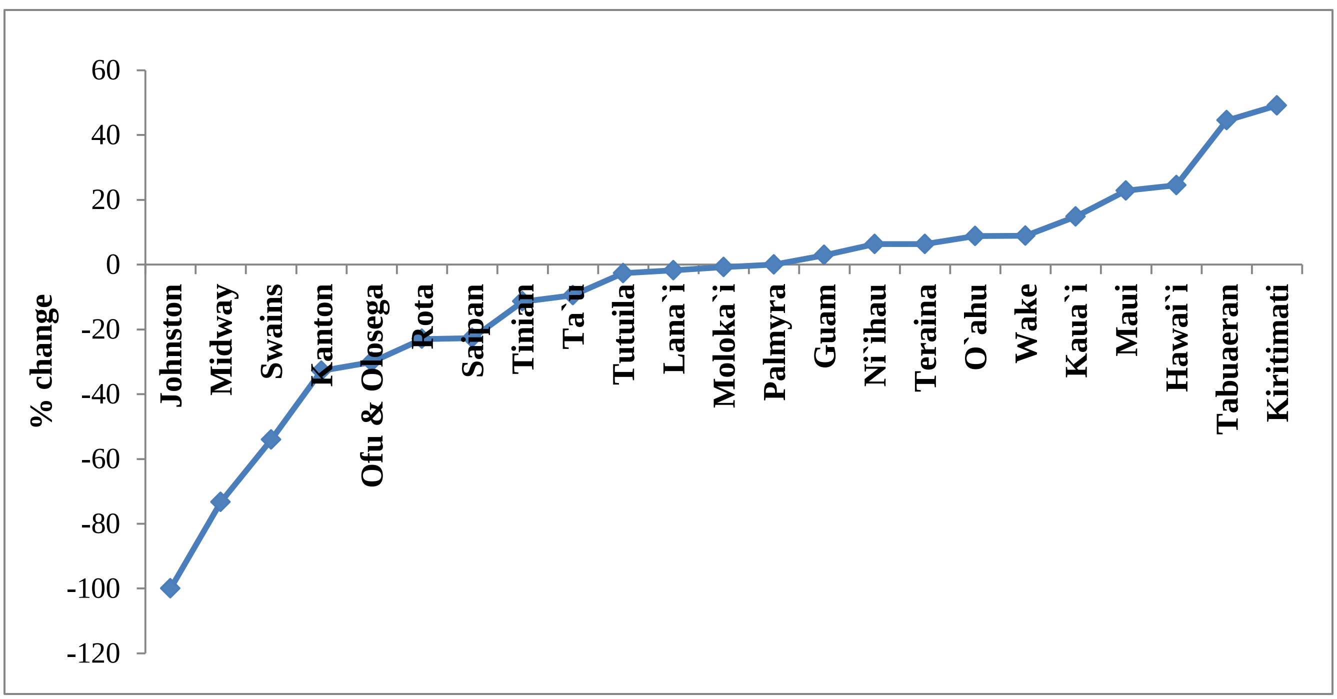

Figure 8. -- Percent population change between 2000 and the most recent census (2010 for U.S.-affiliated islands and 2005 for Kiribati islands).

The main Hawaiian Islands show a slightly different trend, with most of the population increase since 2000 occurring on the islands of Hawai`i (24.5 percent) and Maui (22.8 percent). However, in the case of the state of Hawai`i, while these other islands may not be considered the economic center of the state, they certainly are not remote in the same sense of those of the other territories, such as Ofu and Olosega, which had a population of only 353 people in 2010. O`ahu's population grew at a much slower rate of only 8.8 percent. Newspaper articles suggest that the greater increase in population in Hawai`i Island and Maui are the result of retirees from the mainland and O`ahu moving in, as well as others migrating from the hustle and bustle of Honolulu looking for a more relaxed style of living (Mayer, 2011; Wilson, 2007).

Saipan's population decreased almost 25 percent between 2000 and 2010 (U.S. Census Bureau 2012), and has been greatly impacted by the collapse of the garment industry in the mid-2000s. Beginning in the 1980s, thousands of Asian immigrants moved to Saipan to look for work in the growing garment industry. Because only certain sections of the U.S. naturalization and immigration laws applied to the CNMI, garment manufacturers were able to establish factories there, hire foreign "guest workers" as cheap labor, and sell products duty-free in the U.S. market, branded with a "Made in the USA" label. The establishment of this industry led to the rapid expansion of the CNMI economy and, along with the expanding tourism industry, led to a fourfold increase in population in Saipan from 14,549 in 1980 to 62,392 in 2000 (Malcolm D. McPhee & Associates and Conway, 2008). By the year 2000, almost 17,000 individuals worked in the apparel industry, many of them being foreign workers from the Philippines and China.

Although the CNMI economy and the garment industry were beginning to show signs of decline in the late 1990s, the success of the CNMI garment factories was impaired when China entered the World Trade Organization in 2001 and gained access to American markets in 2005. The CNMI factories were unable to compete with China's very low wage rates, and by 2008 only 3 of the 34 factories that were operating in 2000 remained open (Malcolm D. McPhee & Associates and Conway, 2008). The closure of the factories, along with the decline of tourist arrivals due to a variety of factors including the worldwide economic recession, led to a large retraction in the CNMI economy and ultimately the out-migration of 12,388 people since 2005 (CNMI Central Statistics Division, 2008).

Of the 23 islands and atolls included in this section, the Kiribati islands of Kiritimati and Tabuaeran have the greatest population growth between 2000 and 2005. In 2005, the country of Kiribati had a total population of 92,533, with almost 50 percent of the population living on South Tarawa in the Gilbert Group (not included in this study). Beginning in the 1980s, the Kiribati Government has promoted the migration of residents from the overpopulated Gilbert Group to the Line Islands, especially Kiritimati and Tabuaeran. As a result, the populations of these two islands have each more than doubled since 1990, with especially high rates of population increase since 2000 (49.1 percent for Kiritimati and 44.5 percent for Tabuaeran). In recent years, efforts to increase the population of these two islands are geared toward their development as ecotourism destinations, and government and foreign aid agencies such as the Asian Development Bank are focused on ensuring public facilities, services, and infrastructure are appropriate for the support of the growing population (ADB, 2009).

Population Density

Population density is another metric that has been used to examine the relationships between humans and coral reef health. Table 3 provides population density in terms of land area and reef area for the islands. Figures 9 and 10 show the relationship among the islands in terms of their most recent population estimate (2010 for the U.S.-affiliated islands, 2005 for the Kiribati islands), and their population density in terms of land area (population per square kilometer of total land area of the island) and reef area (population per square kilometer of reef from shoreline to the 30-meter isobaths, from Gove et al. 2013).

As shown in Figures 9 and 10, there is not a consistent relationship between population size and density across the islands in this study. An island with a large population does not necessarily have high land population density (such as Hawai`i); and an island that has high land population density does not necessarily have high reef population density (such as Tabuaeran). Further, an island may have a high level of population (relative to the other islands in the study), but have a relatively low land and reef population density (such as Moloka`i).

In the case of this study area, therefore, ratios of population to land and reef area cannot be assumed to predict consistently the magnitude of human impact on reefs. Because of each island's unique suite of geographical, ecological, and social conditions, the type of population variable that most appropriately represents human impact on reefs for one island might not be the best one to use for other islands. For example, the island of Hawai`i has the second-highest population of the islands in the study. However, because it is also a very large island in terms of land mass, it has a relatively low land population density. In this case, using land population density in analyses to examine the impact of humans on reefs could yield a relatively low measure of impacts on reefs for Hawai`i. However, if we examine on which parts of the island people live, we see that most of the population resides in two specific locations (Kona on the west coast and Hilo on the east coast) on the coasts. In this case, then, it may be more appropriate to use the reef population density specific to certain coasts or areas, since it may give a more realistic picture of the pressure on reefs from people.

If ratios of population to land and reef area are considered together with a variety of ecological variables for this large group of islands comparatively, we may be able to determine which measure of population density is best to use when developing models of human impacts on reefs, regardless of each island's unique characteristics.

Table 3. -- Most recent population estimate (2010 for U.S.-affiliated islands, 2005 for Kiribati islands), population density per square kilometer of land area, and population density per square kilometer of reef area (from Gove et al. 2013) for each island.

	Most Recent Population	**Population Density (Persons per Square Kilometer of Land)**	**Population Density (Persons per Square Kilometer of Reef)**
Johnston	0	0.00	0.00
Swains	17	7.15	6.03
Palmyra	20	8.95	0.38
Midway	40	6.69	0.39
Kanton	41	0.22	*
Wake	135	19.36	7.04
Ni`ihau	170	0.91	1.57
Ofu & Olosega	353	28.00	29.33
Ta`u	790	17.52	76.09
Teraina	1,155	120.94	156.08
Rota	2,527	29.68	157.69
Tabuaeran	2,539	75.27	10.16
Lana`i	3,135	8.58	56.50
Tinian	3,136	30.99	193.61
Kiritimati	5,115	13.17	15.59
Moloka`i	7,345	10.96	37.00
Saipan	48,220	405.28	660.16
Tutuila	54,359	395.48	1,068.21
Kaua`i	66,921	46.58	276.88
Maui	144,444	76.57	733.83
Guam	159,358	292.75	1,680.07
Hawai`i	185,079	17.73	917.74
O`ahu	953,207	615.37	2,254.93

Notes: * Data unavailable. See Table 2 for population data sources.

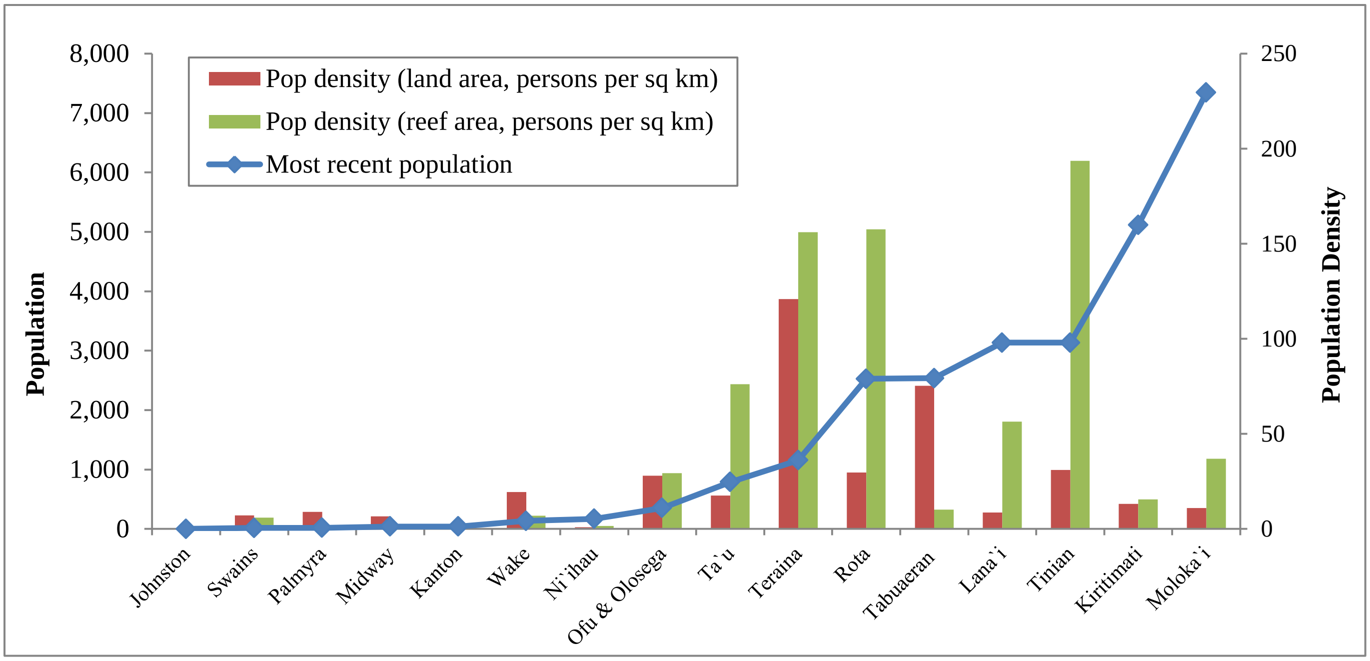

Figure 9. -- Population, population density for land area (persons per km^2), and population density for reef area for the inhabited study islands. Note: The scale on the vertical axis is not the same as that in Figure 10 so as to allow for easier interpretation.

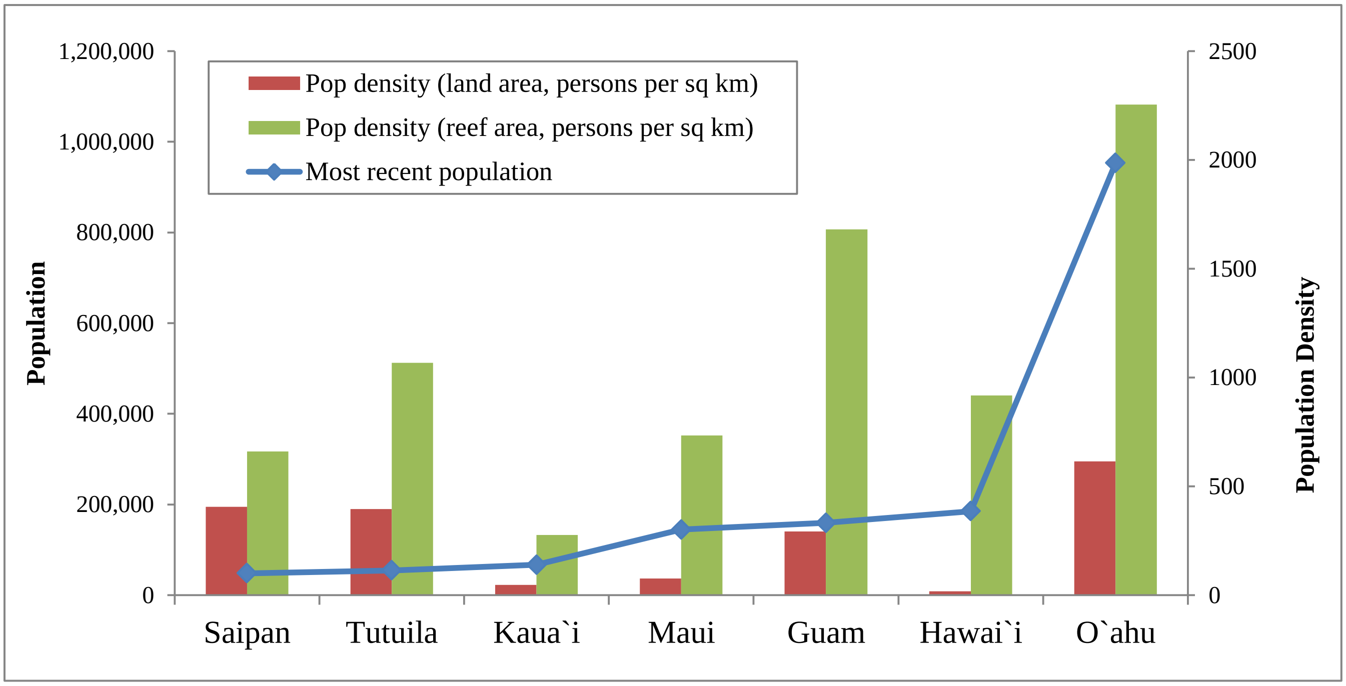

Figure 10. -- Population, population density (persons per km^2) for land area, and population density for reef area for the inhabited study islands. Note: The scale on the vertical axis is not the same as that in Figure 9 so as to allow for easier interpretation.

Visitor Population

It is also important to take the visitor population of each island into account, because often the number of visitors to an island can be much greater than the resident population. Visitors typically stay on an island for only a few days and therefore have different kinds of impacts on coral reefs, such as via recreational activities (e.g., reef trampling while snorkeling) and through their significant contribution to the overall amount of waste produced at specific points in time. Additionally, it is important to consider the visitor population because it accounts for the large number of people who benefit from the economic value of reefs through the tourism and recreational services they provide, such as snorkeling and scuba diving (Cesar et al., 2002; van Beukering et al., 2006).

The islands for which we have visitor statistics are included in Table 4. The two Kiribati islands included, Tabuaeran and Kiritimati, have very small resident populations, as well as the smallest numbers of visitors. This is not surprising, as the islands are very remote, and limited transportation options are available between these islands and the more populated Kiribati Gilbert Islands such as South Tarawa. Although recent efforts by the Government of Kiribati are focused on developing both Tabuaeran and Kiritimati as popular tourist destinations, progress has been slow and their remoteness will likely persist as a limiting factor (ADB, 2009).

Figures 11 and 12 show the islands in terms of their resident and visitor populations. From left to right, they are ordered from smallest to largest resident populations, and one can see that there does not appear to be a direct relationship between population and number of visitors. In some cases, such as Lana`i and Saipan (Fig. 11), islands have relatively low resident populations when compared to the other study islands, but very high numbers of visitors. In other cases however, such as O`ahu (Fig. 12), islands have both high resident populations as well as high numbers of visitors. These figures also make it very easy to see that across all the islands, the overall visitor populations are greater than the resident populations, and for 8 of the 11 islands included here, the visitor populations are more than four times the resident populations. Although these visitors typically stay for only a few days at a time and, therefore, impact reefs in a different manner than full-time island residents, further research must consider the impact these large numbers of visitors have on the islands' reefs.

Table 4. -- Recent population estimates, number of visitors, average length of stay, and visitor days for study islands.

	Most Recent Population	**Number of Visitors**	**Type (method of arrival)**	**Average Length of Stay (in Days)**	**Visitor Days**
Tabuaeran	2,539	165	cruise ship, 2009 [a]	1.00	165
Lana`i	3,135	75,004	air, 2011 [c]	3.52	264,014
Kiritimati	5,115	1,377	air, avg 2005-2009 [a]	7 [g]	9,639
Moloka`i	7,345	55,250	air, 2011 [c]	4.63	255,808
Saipan	48,220	315,588	air, 2011 [d]	3.81	1,202,390
Tutuila	54,359	31,277	air, 2008 [b]	*	*
Kaua`i	66,921	1,011,500	air, 2011 [c]	7.51	7,596,365
Maui	144,444	2,168,487	air, 2011 [c]	8.09	17,543,060
Guam	159,358	918,877	air, 2010 [e f]	3.81	3,500,921
Hawai`i	185,079	1,318,310	air, 2011 [c]	7.35	9,689,579
O`ahu	953,207	4,401,624	air, 2011 [c]	7.38	32,483,985

Notes: See Table 2 for population data sources.
*Data unavailable
[a] Integrated Framework Partnership (2010)
[b] American Samoa Department of Commerce (2009)
[c] Hawai`i Tourism Authority (2011)
[d] Based on analysis conducted with data from MVA (2012)
[e] Guam Bureau of Statistics and Plans (2011)
[f] Visitors staying 30 days or less
[g] 7-day stay assumed based on availability of flights to/from Kiritimati.

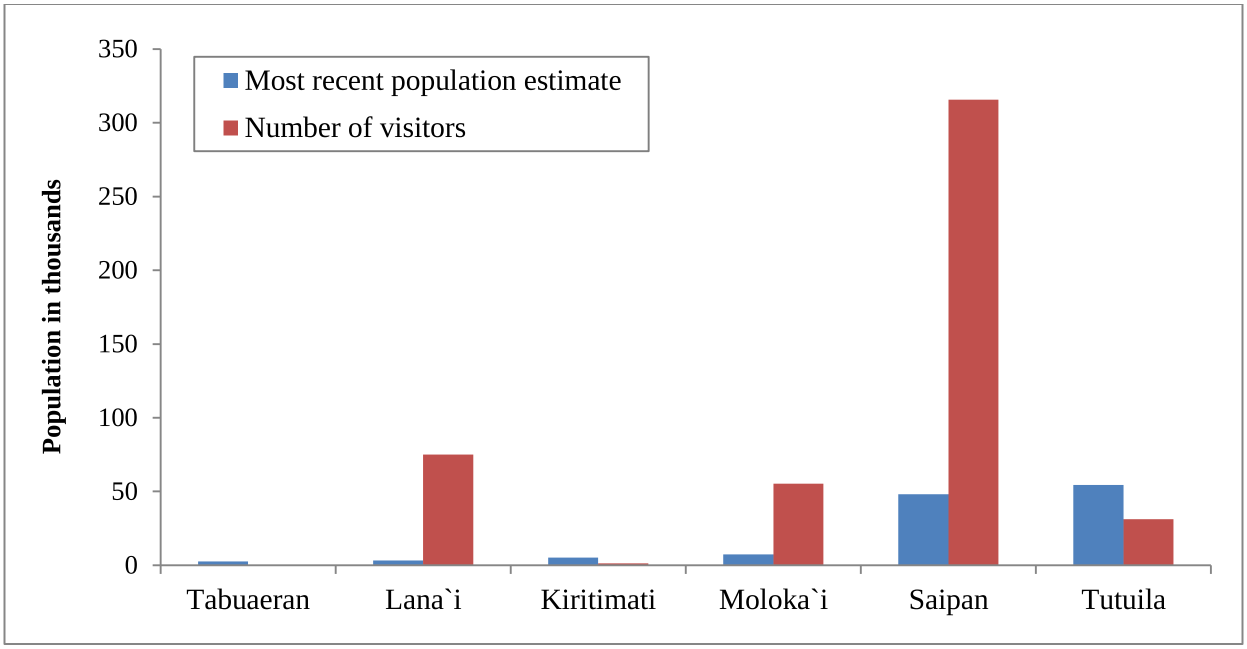

Figure 11. -- Most recent population estimate and number of annual visitors of study islands with small resident populations. Note: The scale on the vertical axis is not the same as that in Figure 12 so as to allow for easier interpretation.

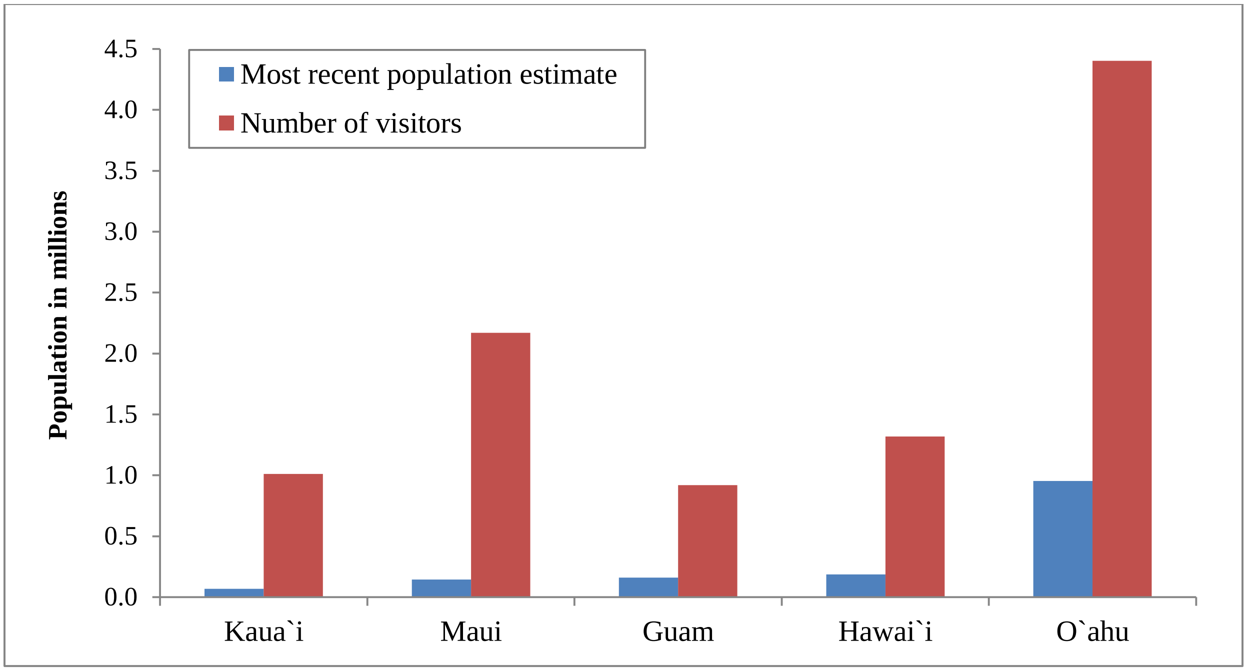

Figure 12. -- Most recent population estimate and number of annual visitors of study islands with large resident populations. Note: The scale on the vertical axis is not the same as that in Figure 11 so as to allow for easier interpretation.

Nativity and Ethnicity

Other demographic data that are relevant when examining the impact of humans on coral reefs are cultural variables such as ethnicity and patterns of migration. Research has shown that ethnicity can impact the health and conservation of natural resources in a variety of ways. For example, resource use may differ depending on the cultural values and environmental ethic associated with a particular ethnic group, the strength of those values regarding the sustainable use of resources, or whether or not resource users are native or migrants to the area (Robbins, 2006; Singleton, 2001; Weber et al., 2007). Research has shown important relationships between nativity or length of residency in a location and factors that are important to the long-term sustainability of natural resources, such as the ability of resource users to self-organize for management purposes and residents' sense of responsibility for the management of natural resources (Berkes et al., 2006; Janssen and Ostrom, 2001; WIOMSA, 2011).

In the case of the islands in this study, demographic data that are available and comparable across islands are very limited. The best data available are those census data (2010 U.S. Census for Hawai`i, 2000 U.S. Census for U.S. territories, and 2005 Kiribati Census for Kiribati islands) regarding the nativity and ethnicity of residents. Table 5 shows the percent of total resident population of each island who were born in the same state, territory, or country in which they are currently living. In this table, we see that two of the islands in CNMI (Saipan and Tinian) have the smallest percentage of native population, while some of the more remote islands in the study, such as Ofu and Olosega in American Samoa and the four Kiribati islands, have the highest percentages.

Table 6 presents data regarding the percentage of the resident population identified as being part of the island's indigenous ethnicity (e.g., Native Hawaiian in Hawai`i) when reporting only one ethnicity, as well as when reporting two or more ethnicities. These percentages are very high for the Kiribati islands, and for most of the American Samoa islands. These data vary greatly for the Hawaiian Islands, with some of the smaller and less-populated islands such as Ni`ihau and Moloka`i having higher percentages of Native Hawaiians. Unsurprisingly, the state's urban economic center—O`ahu—has a lower percentage of Native Hawaiians, partly the result of the large number of Asian migrants throughout the last century. There are two indigenous groups associated with Guam and CNMI—Chamorro and Carolinian. The percentages of Chamorros are much higher for all of the islands of the Mariana Archipelago.

Table 5. -- Percent of the resident population of islands who were born in the same state (Hawai`i), territory (Guam, CNMI, and American Samoa), or country (Kiribati) in which they are currently living.

	Percent of Total Population Born in Same Country, Territory, or State as Currently Living
Saipan	34.5
Tinian	44.7
Maui	51.3
Swains	51.4
Guam	52.2
Rota	52.4
O`ahu	54.7
Tutuila	56.1
Lana`i	57.0
Kaua`i	57.3
Hawai`i	57.6
Moloka`i	73.1
Ofu & Olosega	80.2
Ta`u	83.0
Kanton	95.1
Kiritimati	96.8
Tabuaeran	98.7
Teraina	99.3

Notes: Data for Hawai`i and U.S. territories are from U.S. 2000 Census; data for Kiribati are from Kiribati 2005 Census.

These data are important because in some cases, indigenous groups have been found to utilize traditional ecological knowledge and other long-term cultural knowledge systems to effectively manage natural resources (Berkes, 1999; Johannes, 1978; Stoffle et al., 1994). Resource management in traditional Pacific island societies tends to be holistic in nature, taking into account how the various aspects of ecosystems are interrelated, and engaging those who are highly knowledgeable of local environments and traditional ways of managing and using natural resources (Impact Assessment, 2011). Although many traditional management systems have been destroyed as a result of colonialism and westernization, there is currently a movement among Native Hawaiians to return to more traditional ways of managing resources, including returning to the *ahupua`a*[1] system. Beginning in 2006, the Western Pacific Regional Fishery

[1] According to Impact Assessment (2011): "Ahupua`a are distinct geographic areas, typically bounded by mountain ridges and the ocean. Residents in a given ahupua`a would typically specialize in the knowledge of upland, shoreline, or offshore resources and would cooperate to effectively manage and use those resources within and across the various ahupua`a and moku on a given island. Knowledgeable specialists or konohiki provided guidance to enhance the management and wise use of resources throughout the ahupua`a." (p.iv).

Table 6. -- Percentage of the resident population identified as being part of the island's indigenous ethnicity (e.g., Native Hawaiian in Hawai`i) when reporting only one ethnicity, as well as when reporting two or more ethnicities.

	Indigenous Ethnicity Associated with Island	**1 Ethnicity, Self Reported (%)**	**2 or More Ethnicities, Self Reported (%)**
AMERICAN SAMOA			
Ofu & Olosega	Samoan	97.0	97.4
Swains	Samoan	35.1	35.1
Ta`u	Samoan	95.0	97.3
Tutuila	Samoan	88.1	91.6
CNMI			
Rota	Chamorro & Carolinian	Chamorro: 54.2 Carolinian: 0.1	Chamorro: 62.4 Carolinian: 1.3
Saipan	Chamorro & Carolinian	Chamorro: 18.7 Carolinian: 4.2	Chamorro: 24.6 Carolinian: 7.5
Tinian	Chamorro & Carolinian	Chamorro: 37.3 Carolinian: 0.1	Chamorro: 48.2 Carolinian: 1.9
GUAM			
Guam	Chamorro & Carolinian	Chamorro: 37.0 Carolinian: 0.1	Chamorro: 42.0 Carolinian: 3.6
HAWAI`I			
Hawai`i	Native Hawaiian	8.5	29.7
Kaua`i	Native Hawaiian	7.4	23.9
Lana`i	Native Hawaiian	4.4	19.5
Maui	Native Hawaiian	6.6	21.9
Moloka`i	Native Hawaiian	24.7	61.6
Ni`ihau	Native Hawaiian	85.9	87.6
O`ahu	Native Hawaiian	5.0	19.1
KIRIBATI			
Kanton	I-Kiribati	95.1	95.1
Kiritimati	I-Kiribati	95.1	98.4
Tabuaeran	I-Kiribati	94.9	99.5
Teraina	I-Kiribati	92.6	+ 99.9

Notes: Data for Hawai`i and U.S. territories are obtained from the U.S. 2000 Census; Data for Kiribati are obtained from the Kiribati 2005 Census.

Management Council helped organize the Ho`ohanohano I Nā Kūpuna Puwalu Series with the goal of increasing the participation level of the Hawaiian community in the management of natural resources through a reawakening of attention to *ahupua`a* principles, and through broader representation of Hawaiian needs and interests throughout the islands (Impact Assessment, 2011). In this example, the percentage of the resident population who is Native Hawaiian could be related to the extent to which residents identify with this movement and/or advocate for the return to traditional, sustainable use of resources. As such, it could be an important variable to consider when examining the relationships between humans and reef ecosystems.

While these data regarding nativity and ethnicity are important to examine, one must be aware that it is critical to take each island's context into consideration when attempting to make comparisons. For example, researchers have identified cases (see Hames, 2007) in which traditional management strategies have led to the overexploitation of natural resources (as opposed to sustainable use). Additionally, studies have shown there are a variety of demographic, social, and economic factors that impact the manner in which natural resources are used and conserved, regardless of residents' ethnicity or place of birth (Cinner and McClanahan, 2006; Pollnac et al., 2000; Turner et al., 2007).

REEF FISHING PRESSURE

This section describes and compares the islands in the study in terms of estimated reef fishing pressure. Recent studies suggest that reef fishing can significantly impact coral reef fish assemblages as well as the coral reef ecosystem as a whole (Brewer et al., 2009; Williams et al., 2011). However, fishing also plays an important nutritional, social, cultural, and economic role for those who live in many of the study locations. It is critical, therefore, to accurately assess the reef fishing pressure in these locations to better understand how impacts from reef fishing compare with other anthropogenic factors, such as land-based sources of pollution.

Currently, the reef fish catch data available for the Pacific Islands in this study are limited. Despite this lack of data, this analysis explores the utility of developing a reef fishing pressure scale to allow for cross-island comparisons. Additionally, this analysis compares the islands' population data with their reef fishing pressure scale rankings, and describes other factors that should be taken into consideration when estimating reef fishing pressure, such as economic development trends and cultural dietary preferences.

Reef Fishing Pressure Scale

This indicator represents the relative reef fishing pressure on the islands and atolls included in this study. For this indicator, a scale was developed that indicates relative level of reef fishing pressure using the limited reef fish landings data available. As shown in Table 7, each reef location was given a score of 0 – 3, where a score of 0 represents the lowest level of reef fishing pressure and 3 represents the highest. For locations where reef fish landings estimates were available (Table 8), those data were used to place the locations along the scale. For these locations, divisions in the scale (e.g., the difference between 1 and 2) are based on natural breaks

Table 7. -- Scale of reef fishing pressure.

Island/Atoll/Reef	Archipelago	Fishing Pressure	Island/Atoll/Reef	Archipelago	Fishing Pressure
Agrihan	Marianas	0	Santa Rosa	Marianas	0
Alamagan	Marianas	0	Sarigan	Marianas	0
Anatahan	Marianas	0	South Bank	Samoa	0
Arakane	Marianas	0	Starbuck	Line	0
Asuncion	Marianas	0	Stingray	Marianas	0
Baker	Phoenix	0	Supply	Marianas	0
Caroline	Line	0	Swains	Samoa	0
Enderbury	Phoenix	0	Tatsumi	Marianas	0
Flint	Line	0	Uracas	Marianas	0
French Frigate	NWHI	0	Vostok	Line	0
Gardner	NWHI	0	Wake	Marshalls	0
Guguan	Marianas	0	Zealandia	Marianas	0
Howland	Phoenix	0	Five Fathom	MHI	1
Jarvis	Line	0	Ka`ula	MHI	1
Johnston	Line	0	Lehua	MHI	1
Kingman	Line	0	Ni`ihau	MHI	1
Kure	NWHI	0	Lana`i *	MHI	1
Laysan	NWHI	0	Kanton	Phoenix	1
Lisianski	NWHI	0	Molokini	MHI	1
Malden	Line	0	Moloka`i *	MHI	1
Maro Reef	NWHI	0	Kaua`i *	MHI	2
Maug	Marianas	0	Hawai`i *	MHI	2
McKean	Phoenix	0	Tutuila *	Samoa	2
Midway	NWHI	0	Maui *	MHI	2
Necker	NWHI	0	Ofu & Olosega *	Samoa	2
Nihoa	NWHI	0	Ta`u	Samoa	2
Nikumaroro	Phoenix	0	Rota	Marianas	2
Orona	Phoenix	0	Saipan *	Marianas	2
Pagan	Marianas	0	Tinian	Marianas	2
Palmyra	Line	0	Aguijan	Marianas	2
Pathfinder	Marianas	0	Guam *	Marianas	3
Pearl & Hermes	NWHI	0	O`ahu *	MHI	3
Raita Bank	NWHI	0	Kiritimati *	Line	3
Rawaki	Phoenix	0	Tabuaeran *	Line	3
Rose	Samoa	0	Teraina *	Line	3

Note: * Denotes islands for which landings data are available. See Table 8.

in the distribution of reported kilograms landed. For the other locations, other forms of data were used for categorization, including: qualitative data regarding reef fishing in particular locations, population, proximity to other populated islands, type of economy (cash-based vs. subsistence), and fish consumption rates.

For some of the unpopulated, most remote islands in the study (such as Kure or Rawaki), it is possible there is no reef fishing that occurs in the vicinity. However, because these areas are so remote and are not monitored at all times, one cannot say that absolutely no fishing occurs. These islands were assigned a score of 0. Islands that have very small populations, such as Johnston or Palmyra Atolls, likely feature a very limited amount of fishing and also were assigned a score of 0. A score of 1 represents fishing pressure ranging from approximately 500 to 9,000 kilograms per year; a score of 2 represents fishing pressure ranging from approximately 9,000 to 65,000 kilograms per year; and a score of 3 represents the highest level of fishing pressure—anything over 65,000 kilograms per year.

Table 8. -- Available reef fish landings data for study islands.

Island/Atoll/ Reef	Est. Reef Fish Catch (kg).	Reference	Data Collection Method	Data Collection Period
Lana`i	969	Luck & Dalzell, 2010	CML logbook data	2005–2009
Moloka`i	2,960	Luck & Dalzell, 2010	CML logbook data	2005–2009
Kaua`i	15,045	Luck & Dalzell, 2010	CML logbook data	2005–2009
Hawai`i	30,365	Luck & Dalzell, 2010	CML logbook data	2005–2009
Tutuila	30,824	Luck & Dalzell, 2010	WPacFIN creel survey	2004–2008
Maui	33,487	Luck & Dalzell, 2010	CML logbook data	2005–2009
Ofu & Olosega	37,500	Craig et al., 2008	independent creel survey	2002–2003
Saipan	42,108	Luck & Dalzell, 2010	WPacFIN creel survey	2005–2008
Guam	88,017	Luck & Dalzell, 2010	WPacFIN creel survey	2005–2008
O`ahu	139,650	Luck & Dalzell, 2010	CML logbook data	2005–2009
Kiritimati	296,670	Awira et al., 2008	socioeconomic surveys and interviews	2004
Tabuaeran	926,304	Preston, 2008; ref. Lovell et al., 2000	Kiribati Fisheries Division artisanal fishery surveys	2000
Teraina	1,121,424	Preston, 2008; ref. Lovell et al. 2000	Kiribati Fisheries Division artisanal fishery surveys	2000

Several points must be made regarding this scale of reef fishing pressure. First, it is important to note that actual landings data and landings estimates are only available for a small number of the study locations (13 out of 70). While many of the locations without these data are uninhabited, isolated reefs and atolls where it is reasonable to assume that very little reef fishing (if any) occurs, others are populated islands (such as Rota) that simply do not have any methods in place to monitor and account for the reef fishing that occurs. Because of this, the categorization shown in Table 7 is largely the result of the researcher making assumptions as to where to place locations on the scale.

Secondly, there is a lack of consistency regarding the methods used to obtain the data shown in Table 8. For example, a creel survey was used to determine the landings data for the islands of Guam, Tutuila, and Saipan (WPacFIN), while the landings data for the islands of Lana`i, Moloka`i, Kaua`i, Hawai`i, Maui, and O`ahu come from the Hawai`i Commercial Marine License logbooks that all commercial fishermen are required to submit to the State of Hawai`i Division of Aquatic Resources (HDAR, 2010). Even among the islands that conduct similar creel survey programs, as in the case of the three previously mentioned US-affiliated islands, the operational procedures and protocols used vary a great deal across islands, thereby yielding data that may not be comparable to one another (Bak, 2012). Additionally, the estimated reef fish catch data presented for three of the four inhabited Kiribati islands were not derived from the same methods. The data from Tabuaeran and Teraina are taken from Lovell et al. 2000, and were determined through artisanal fishery surveys conducted by the Kiribati Fisheries Division (Lovell et al., 2000), while the data for Kiritimati were determined using average fish consumption rates assessed through household income and expenditure surveys (Awira et al., 2008). Although the data used to develop this scale are considered to be the best available island-scale data, these inconsistencies in methodology suggest that the comparative value of these data is limited.

Population and Fishing Pressure

Total fisheries landings data are often unavailable or limited from less-developed and more remote locations (including several of the sites in this study). One approach that can be used to estimate an overall reef fish catch level for a community, island, or country is to multiply a per-person catch rate or fish consumption rate (as determined by a particular study) by the total population. However, several social, cultural, and economic factors can contribute to variation in the extent to which people fish for, catch, and consume reef fish across the islands and territories in this study, and even across communities within the same island. This section compares the study islands in terms of estimated reef fishing pressure and total population, and evaluates the extent to which population size is correlated with the amount of reef fish caught.

Using the estimated reef fish catch data from Table 8, Figure 13 shows the relationship between several islands' estimated catch and population. A visual review of a plot of these data suggests that an increase in human population is not necessarily indicative of an increase in reef fish catch. Further, correlation analysis yielded a Pearson's r of - 0.157 (p = .608), suggesting very little correlation between catch and population size.

One interesting case highlighted by this study is American Samoa. Although Tutuila has a much higher population (54,359) than Ofu & Olosega (353), the estimated reef fish catch for Tutuila is lower (30,824 kg) than that for Ofu & Olosega (37,500 kg). Several studies (Craig et al., 1993; 2008; Sabater and Carroll, 2009) have described the relationship between declines in catch and effort in the shoreline subsistence fishery and the shift in Tutuila from a subsistence economy to a cash economy that occurred since the 1950s. Societal changes have been documented in Tutuila related to this shift, including a decreasing reliance on local fish for food, an increasing preference to buy fish at the market as opposed to putting effort toward fishing, a decrease in leisure time, and a shift in dietary preferences towards store-bought food (Levine and Allen, 2009). Such dietary changes are common in societies undergoing such a transition, and the World Health Organization has documented similar cases throughout the Pacific Islands (WHO, 2003).

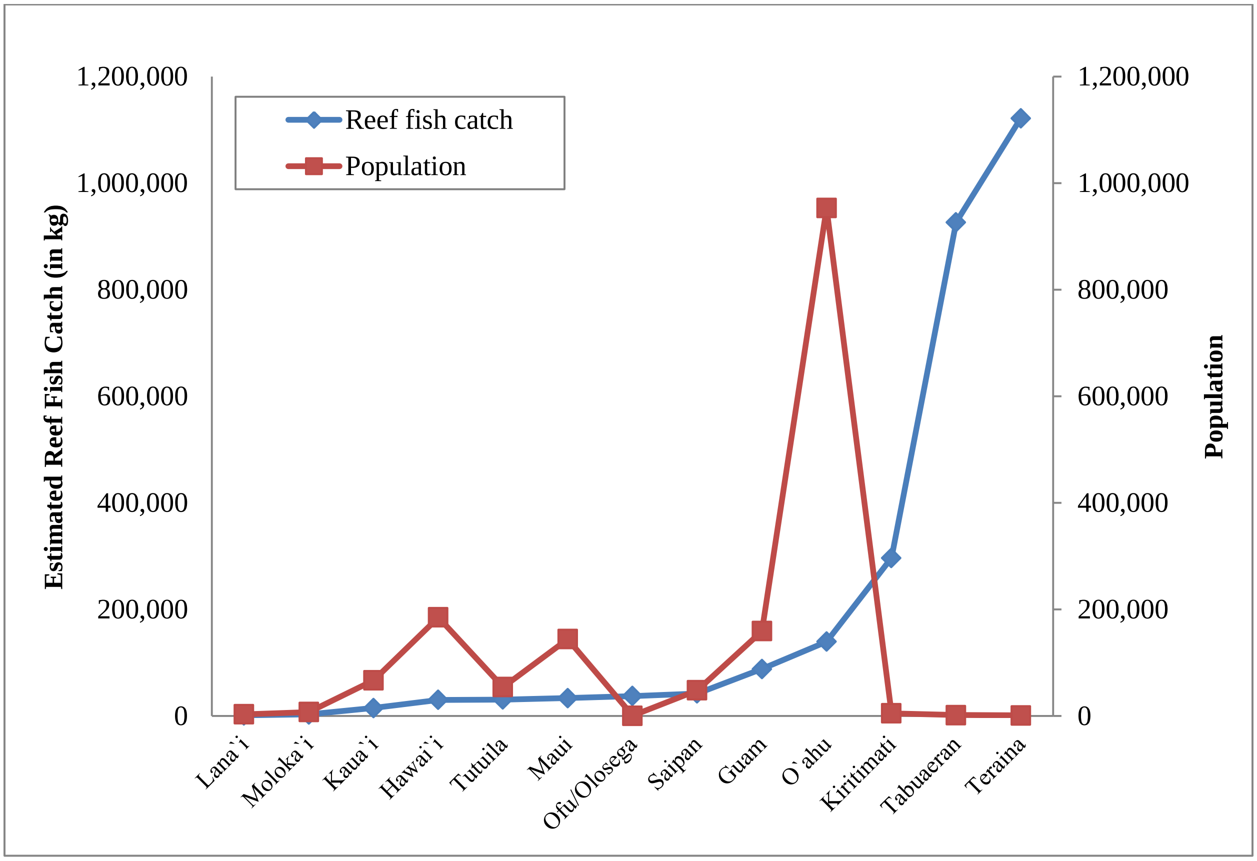

Figure 13. -- Relationship between estimated reef fish catch (in kilograms) and resident population.

While this decrease in dependence on subsistence fishing has been seen in Tutuila, it is not the case in the outer Manu`a Islands of American Samoa. Craig et al.'s (2008) survey of shoreline fishing showed that although the Ofu & Olosega fishery was small-scale and there were no "full-time" fishermen, fishing was a low-level but steady activity conducted throughout the year that contributed significantly to the diets of villagers. Compared with Tutuila, villagers in Ofu & Olosega have more limited access to imported foods and store-bought products. Although Craig et al. suggest that even in these more remote islands, the fishery is shifting to include the sale of some fish both locally as well as off-island, the continued dependence on fish for food certainly contributes to the difference in catch between the highly-populated Tutuila and the more remote Ofu & Olosega.

A similar situation can be seen in the remote Kiribati islands of Kiritimati, Teraina, and Tabuaeran. Several reports have focused on the lack of local resources available in Kiribati. Essentially, their only local resources are those that come from the sea, and Kiribati as a country is estimated to have one of the highest fish consumption levels in the world (Diffey and Gillett, 2008; Lovell et al., 2000). On the outer islands such as Kiritimati, Teraina, and Tabuaeran that are far from Kiribati's population center in the Gilbert Islands, alternate sources of food must be imported at a very high cost, and it is not surprising that residents are highly dependent on reef fisheries resources as their most important protein and nutrition source (Awira et al., 2008). A study conducted in Kiritimati in 2008 found that 92 percent of households were actively involved in reef fisheries. While there is a small commercial export market for reef fish in Kiritimati, the study found that 80 percent of the reef fish catch is used for subsistence (Awira et al., 2008). These case studies suggest that it may be inappropriate to assume that the ratio of population to fishing pressure is fixed across islands, even within the same archipelago. Larger populations do not always correlate to greater fishing pressure on a given reef area. As suggested by these data, other factors can contribute to the extent to which island residents utilize reef resources, such as the availability of alternative food resources or easy access to market goods. Further research is needed to uncover how these socioeconomic factors interact with other ecological and cultural factors and impact reef fishing pressure throughout the islands and atolls in the region of study.

LAND AND WATERSHED ALTERATIONS

Many major coral reef ecosystem stressors, such as toxicants, sediments, and nutrients, originate from land-based sources. Often, these stressors are the result of human-induced watershed alteration, run-off, and coastal development, which in turn can cause disease and mortality of coral reef associated species, alter sensitive ecological functions, and disrupt growth, reproduction, and larval settlement of corals (Fabricus, 2005; ISRS, 2004). Many of the coral reefs in the world are found in desirable tourist destinations, such as the Caribbean and tropical Pacific, causing these reefs to be threatened by coastal development and general watershed alteration associated with the building and maintenance of resorts and other tourist attractions such as golf courses. In addition, many of the islands in this study have also experienced human-induced changes to watersheds and drainage basins as a result of agriculture, deforestation, feral grazing, fires, and urbanization (State of Hawai`i, 2010; Waddell and Clarke, 2008). Many of these effects are exacerbated by issues particular to tropical island areas, such as high levels of rainfall, extreme weather events (e.g., hurricanes, typhoons), highly erodible soils, limestone hydrologic features (specific to Pacific atolls), and steep slopes adjacent to the coastline (such as in American Samoa) (CRCP, 2011). This section compares the study sites by examining the relationship between reef health and the degree of land alteration and sanitation infrastructure.

Land Cover

Land cover data are often examined to understand what types of land and watershed alterations have occurred in a given area, including the extent to which runoff and the resulting introduction of sediment and pollutants into nearshore areas might occur. There were no island-scale data available that were comparable across all the islands in this study. The data presented here compare a subset of the islands using land cover data, particularly in terms of the percent of total land area that is impervious surfaces (areas that water cannot penetrate), cultivated land, and pasture. These attributes were selected because they are linked to the amount and type of runoff that occurs (Derse et al., 2007; Oliver et al., 2011). Although not all impervious surfaces are manmade (some soil and rock types are naturally impervious), most are associated with development, such as rooftops, roads, and parking lots. Rainwater washing over these surfaces collects sediment, debris, residue, and other pollutants, and they are washed into streams and eventually drained into soil and groundwater or coastal waters. Agricultural lands, including cultivated land and pastures, are also linked to coral reef degradation through soil erosion and the subsequent introduction of sediments, nutrients, and pollutants into coastal waters (Mora, 2008; Waddell, 2005).

Table 9 presents land area and land cover data for the islands in this study that are part of NOAA Coastal Services Center's Coastal Change Analysis Program (C-CAP). O`ahu has the highest percentage of impervious surfaces at 12.2 percent of the total land area, followed by Guam and Tutuila, with 8.3 percent and 4.9 percent, respectively. This is not surprising, as these are the most developed islands in each of the island areas.

In terms of cultivated and pasture lands, the Hawaiian Islands have the highest percentages of lands devoted to these uses. Maui has the highest percentage of cultivated lands (11.5 percent), with coffee, macadamia nuts, papaya, tropical flowers, sugar, and fresh pineapple as major agricultural exports. Hawai`i and Ni`ihau have the largest percentages of pasture land (14.7 percent and 14.6 percent, respectively) used for grazing animals, primarily cattle. Most of the territorial islands for which there are C-CAP data have negligible percentages of their lands devoted to these uses. Tutuila has the highest percentage of cultivated land at 1.9 percent, and Tinian has the highest percentage of pasture lands at 4.4 percent.

The following figures show, for the islands from Table 9, the relationship between each island's total land area and percentage of impervious surfaces (Fig. 14), percentage of cultivated land (Fig. 15), and percentage of pasture lands (Fig. 16). From these figures, one can see that there is no direct relationship between the total land area of the islands and the percent of impervious surfaces, cultivated lands, or pasture lands. This is because there are several factors that may impact the land cover and land use of an island, such as the resident and visitor population, the typography of the island, or the fertility of the soil.

Table 9. -- Regional land area and land cover data for the islands included in NOAA Coastal Services Center's Coastal Change Analysis Program (C-CAP).

	Land Area (sq. km.)	**Impervious Surfaces (%)**	**Cultivated Crops (%)**	**Pasture/Hay (%)**	**Year of Data**
HAWAI`I					
Hawai`i	10,441.51	1.0	1.6	14.7	2005
Maui	1,886.32	3.0	11.5	5.8	2005
Lana`i	365.37	1.0	0.1	0.3	2005
Moloka`i	670.22	0.8	1.6	5.9	2005
O`ahu	1,548.99	12.2	5.8	0.0	2005
Kaua`i	1,436.70	2.5	4.8	6.3	2005
Ni`ihau	186.82	0.6	0.0	14.6	2005
AMERICAN SAMOA					
Tutuila	137.45	4.9	1.9	0.1	2003
Swains	2.38	0.1	0.0	0.0	2002
Rose	0.09	0.0	0.0	0.0	2002
Ta`u	45.09	0.7	0.1	0.0	2004
Ofu & Olosega	12.61	1.0	0.2	0.0	2004
GUAM					
Guam	544.34	8.3	0.5	0.0	2005
CNMI					
Agrihan	44.05	0.0	0.0	0.0	2001
Aguijan	7.01	0.0	0.0	0.0	2003
Alamagan	12.96	0.0	0.0	0.0	2007
Anatahan	33.28	0.0	0.0	0.0	2005
Asuncion	7.86	0.0	0.0	0.0	2004
Guguan	4.24	0.0	0.0	0.0	2004
Maug	2.14	0.0	0.0	0.0	2003
Pagan	47.75	0.0	0.0	0.0	2005
Uracas	2.25	0.0	0.0	0.0	2004
Rota	85.13	2.5	1.0	2.3	2005
Saipan	118.98	3.5	0.4	0.1	2005
Sarigan	4.47	0.0	0.0	0.0	2006
Tinian	101.21	3.5	0.6	4.4	2005

Notes: According to C-CAP: "Impervious surfaces are paved or compacted surfaces due to man (concrete, asphalt, and other constructed materials)" (NOAA Coastal Services Center, pers. comm.); Cultivated crops are "areas intensely managed for the production of annual crops. Crop vegetation accounts for greater than 20 percent of total vegetation. This class also includes all land being actively tilled;" Pasture/Hay areas are "areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle and not tilled. Pasture/hay vegetation accounts for greater than 20 percent of total vegetation." (NOAA Coastal Services Center, n.d.)

Figures 17 – 19 show there also are no direct relationships between the total population of an island and the percentage of impervious surfaces, cultivated lands, or pasture lands. For example, looking at Figure 17, one sees that some of the islands with larger populations, such as Guam and O`ahu, do in fact have greater percentages of impervious surfaces. However, other islands do not follow this pattern, as with the island of Hawai`i. Although the island of Hawai`i has the second-largest population of all the islands in the study, it is much larger in land area than any of the other islands, and so the percentage of impervious surfaces is much lower relative to the other islands. Figure 18 offers another example of how the particular characteristics of an island, such as the high percentage of pasture lands on Ni`ihau and Hawai`i, must be taken into consideration when examining relationships between total population, land cover, and the potential impacts on coral reefs.

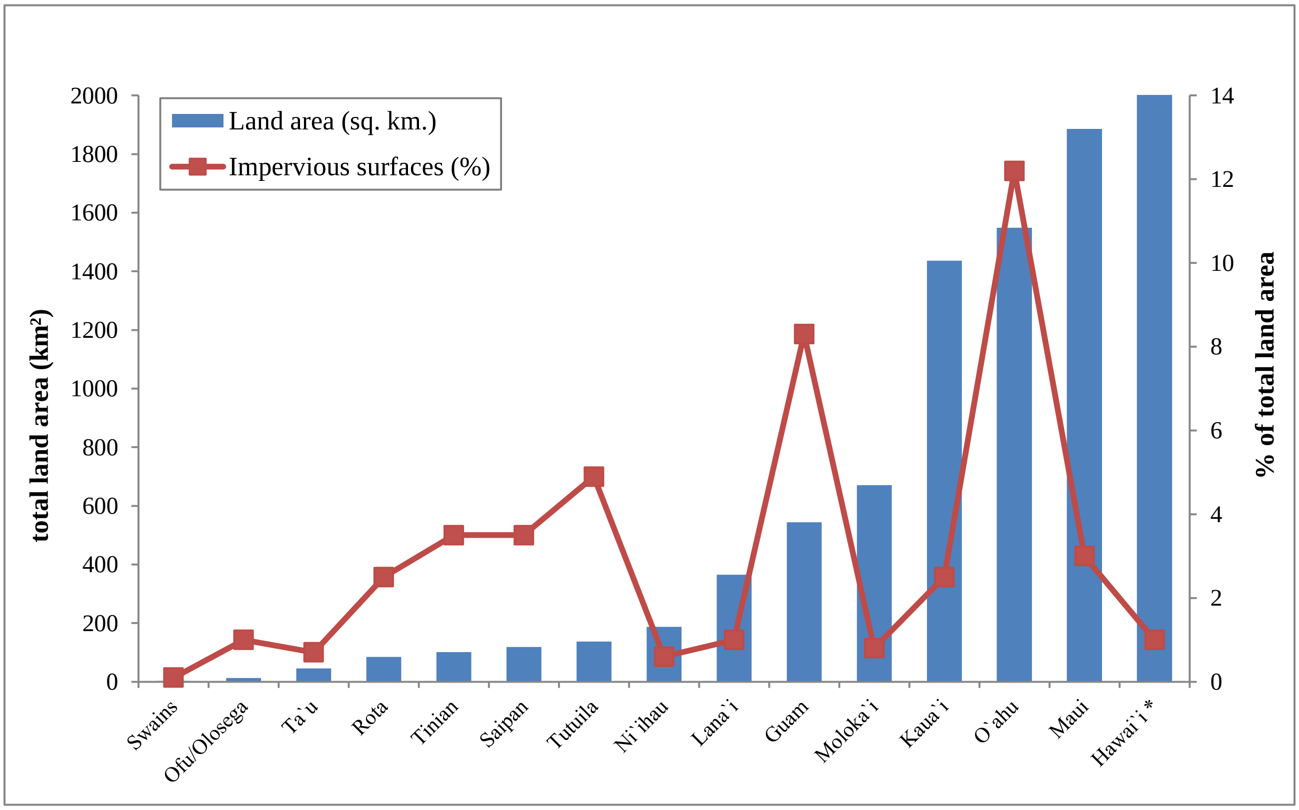

Figure 14. -- Total land area and percent of total land area that is impervious surfaces. Note: *Total land area for Hawai`i island (approximately 10,442 km^2) is out of range of this graph.

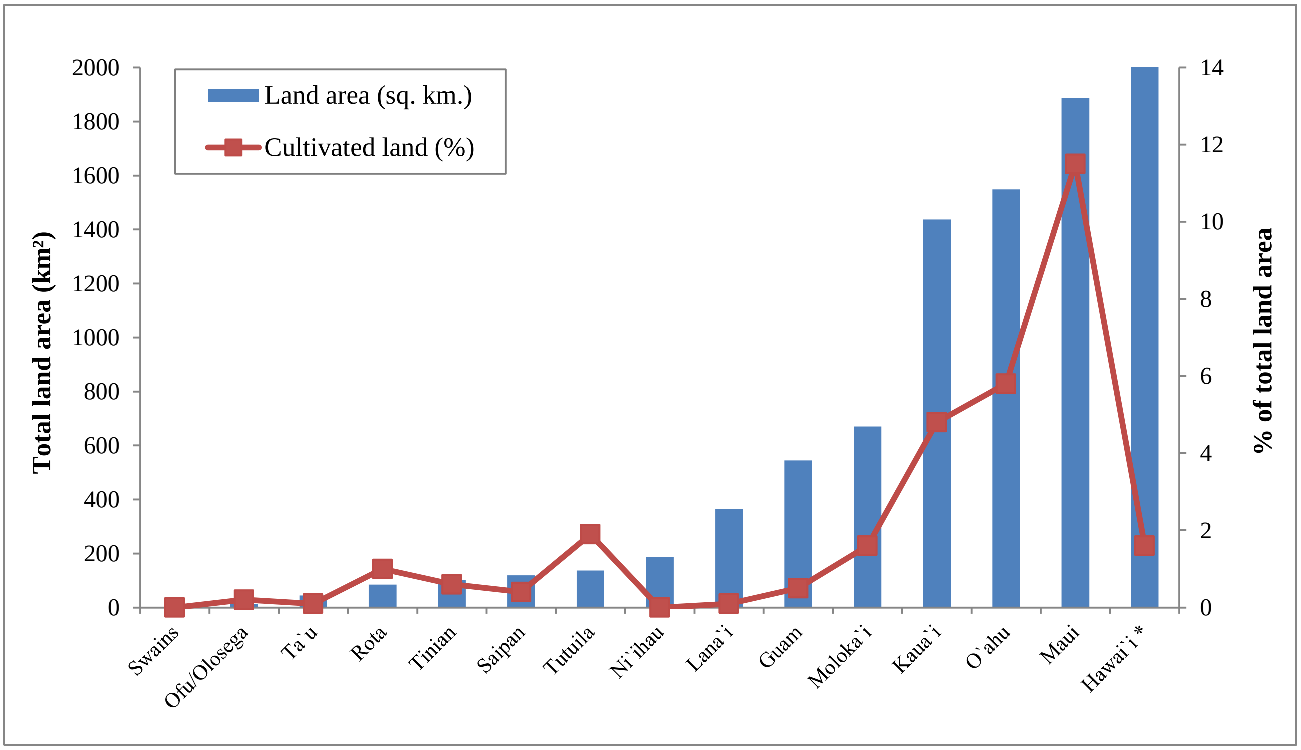

Figure 15. -- Total land area and percent of total land area that is cultivated lands. Note: *Total land area for Hawai`i island (approximately 10,442 km^2) is out of range of this graph.

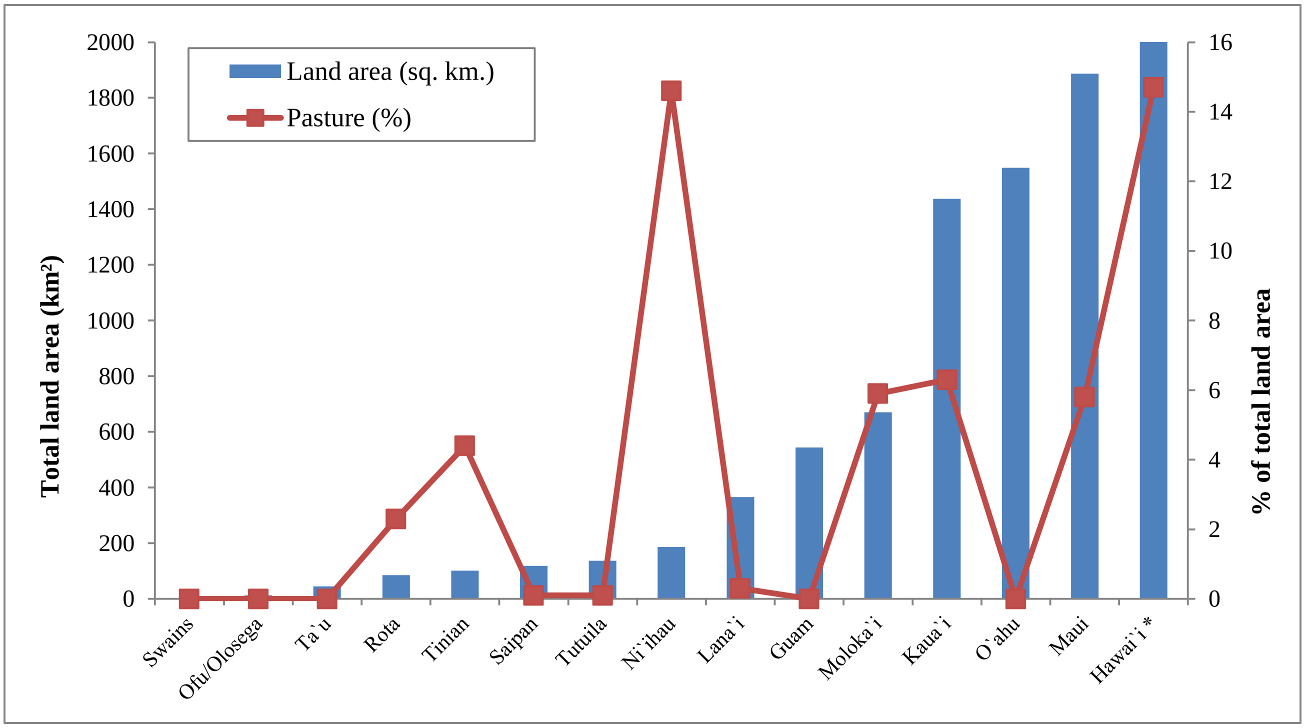

Figure 16. -- Total land area and percent of total land area that is pasture lands. Note: *Total land area for Hawai`i island (approximately 10,442 km^2) is out of range of this graph.

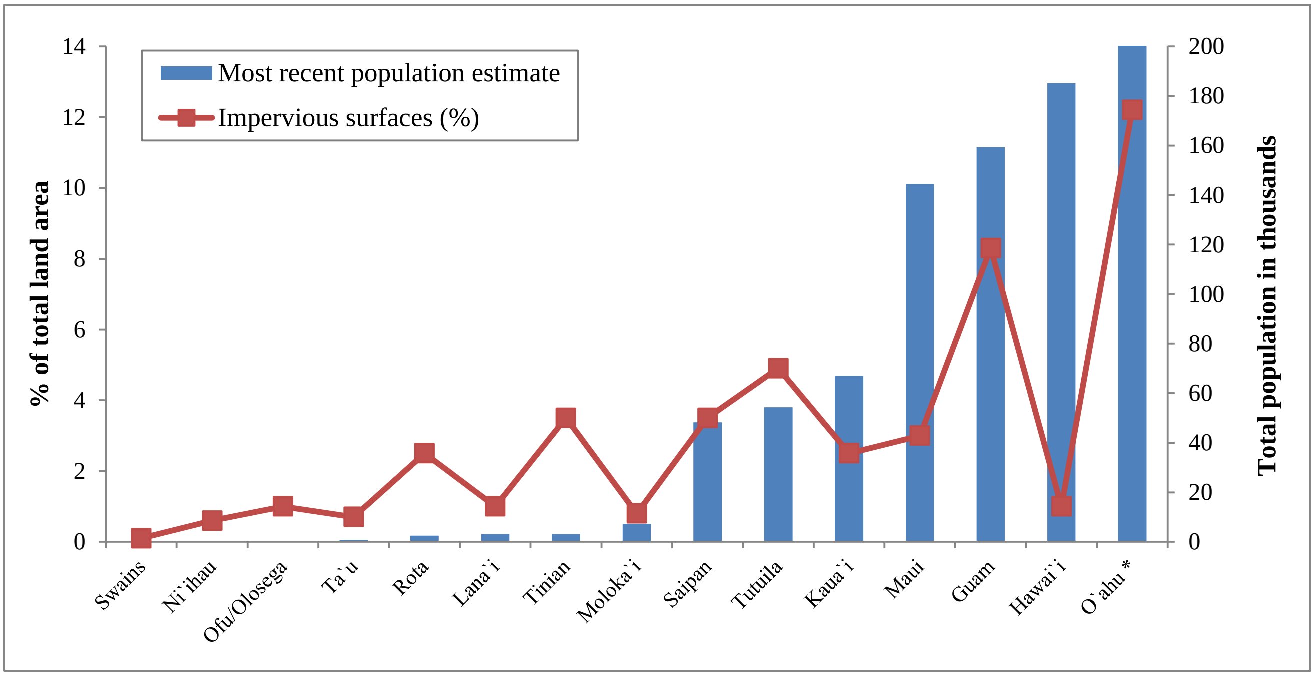

Figure 17. -- Most recent population estimate and percent of total land area that is impervious surfaces.
Note: *Total population for O`ahu (953,207 people) is out of range of this graph.

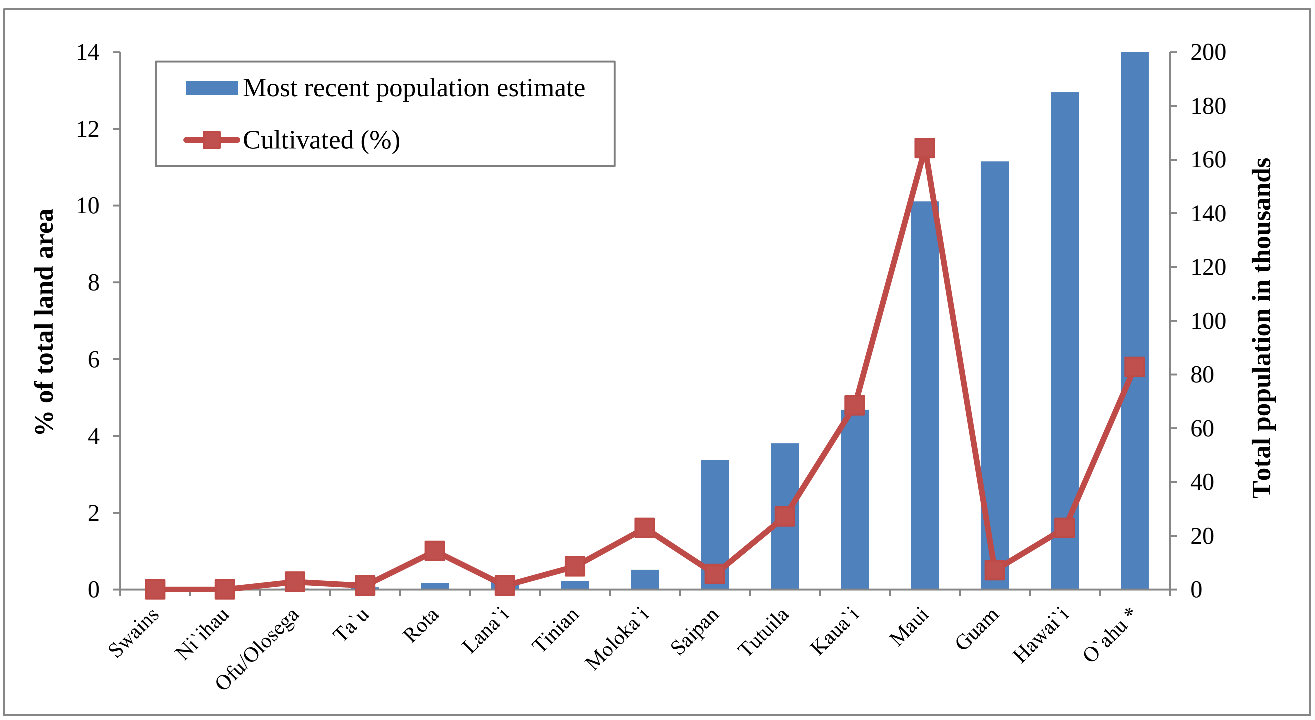

Figure 18. -- Most recent population estimate and percent of total land area that is cultivated.
Note: *Total population for O`ahu (953,207 people) is out of range of this graph.

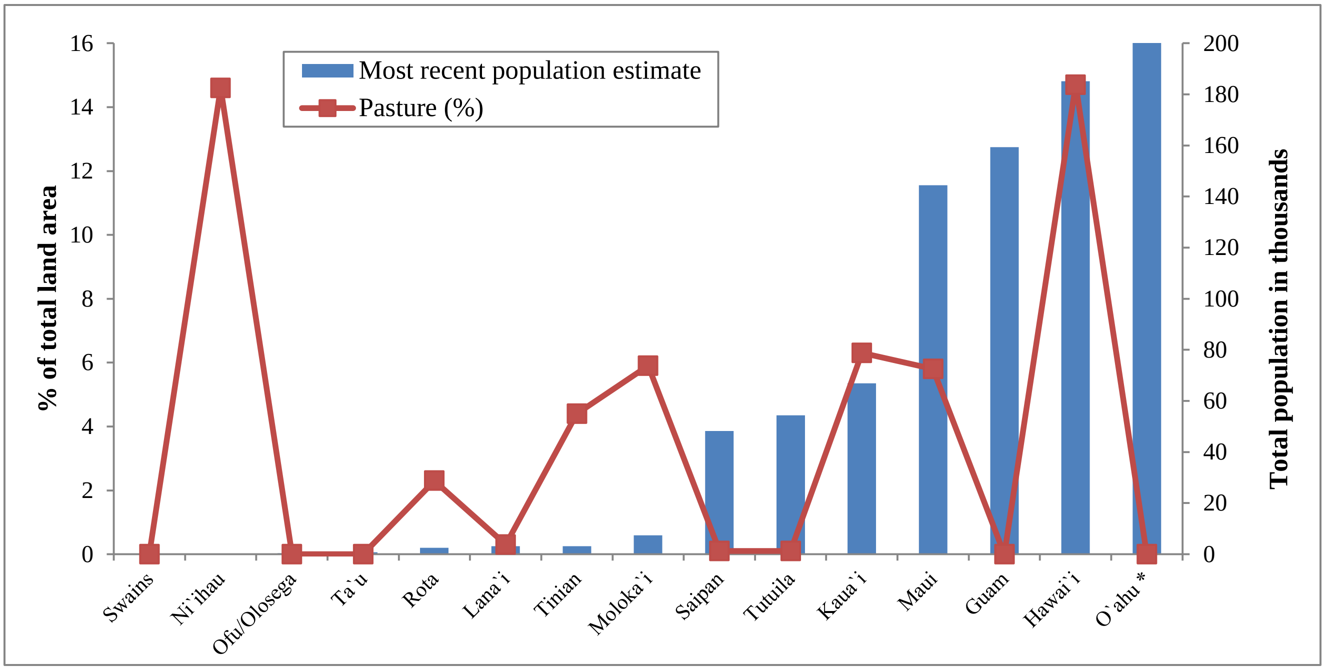

Figure 19. -- Most recent population estimate and percent of total land area that are pasture lands.
Note: *Total population for O`ahu (953,207 people) is out of range of this graph.

To compare the U.S.-affiliated islands with the Kiribati islands in terms of land cover, data from the Food and Agriculture Organization (FAO) and the World Health Organization (WHO) of the United Nations were used. However, these data are not available at the island scale, and so the data presented in Table 10 are at the territory or country scale. According to these data, Kiribati has the highest percentage of permanent crops (39.5 percent) when compared with the U.S. territories. However, it is important to remember that these data also include the lands of the 16 Gilbert Islands, which are part of the nation of Kiribati but not included in this study. Although more than 90 percent of the Kiribati population reside in the Gilbert Islands, several sources suggest residents of the four Kiribati islands in this study (Kiritimati, Teraina, Kanton, and Tabuaeran) grow their own food crops as well as produce copra for export, so it is likely the study islands have a significant amount of permanent crops (ADB, 2007; Morrison and Woodroffe, 2009; SPC, 2007).

Another important point that must be made is that these island-scale data mask the localized impacts that land-based sources of pollution (due to runoff, sedimentation, and the introduction of nutrients, toxins, and other pollutants) can have on coral reefs adjacent to watershed drainages or other source points. Several factors can affect the amount of runoff and the rate of sedimentation that occurs at any given point on the coastline, including the topography of the watershed, level of urbanization and development, and the amount and type of ground cover/vegetation, and this can vary a great deal from one side of an island to another, and even from watershed to watershed. Additionally, coastal development such as seawalls can affect coral reefs directly by altering wave, current, and sand deposition patterns.

Table 10. – Percentage of land area used for permanent crops.

	% Permanent Crops *
American Samoa	15.0
CNMI	2.2
Guam	18.5
Kiribati	39.5

Note: * According to the FAO, "permanent crops" land "is the land cultivated with long-term crops which do not have to be replanted for several years (such as cocoa and coffee)" (FAO, 2012).

Although the data needed for these kinds of analyses are not available for most of the islands in this study, in Hawai`i, a recent partnership between NOAA Pacific Islands Fisheries Science Center's Human Dimensions Research Program (HDRP), the Coral Reef Ecosystem Division (CRED), and Michigan State University (MSU) is building on Native Hawaiian practices in order to link anthropogenic land-based disturbances to coral reef ecosystems at the watershed level. Native Hawaiians used a place-based, ecosystem approach to manage natural resources. Islands, which were called *mokopuni*, were divided into districts called *moku*. *Moku* were further divided into *ahupua`a,* pie-shaped sections of land that extended from the mountains to the coastal zone and out into the fishing grounds, or *ko`a*, and followed the natural boundaries of the watershed. Each *ahupua`a* contained a wide range of natural resources, with all residents cooperating to produce food, tools, medicines, and other items needed for survival (NMFS, 2009).

In Hawai`i, current management efforts are returning to the Native Hawaiian *ahupua`a* or "ridge to reef" approach for managing watershed resources. Through the partnership mentioned above, scientists and managers are building on an assessment of watershed disturbances in the MHI completed in 2010 by scientists at MSU. Although the original assessment was part of the National Fish Habitat Partnership (NFHP)[2], the current pilot effort is extending this analysis to include coastal areas. To do so, researchers are linking marine biological data (such as coral cover, coral density, and macroalgae cover) collected through CRED and HDAR surveys with land-based disturbance data (such as urban lands, former plantation land area, and point source pollution) resulting from the NFHP work in Hawai`i. The project will serve as a pilot study in Maui, using GIS (Fig. 20) to determine the most effective way to link these various data and to understand how the data can be used to support watershed management.

[2] http://fishhabitat.org/

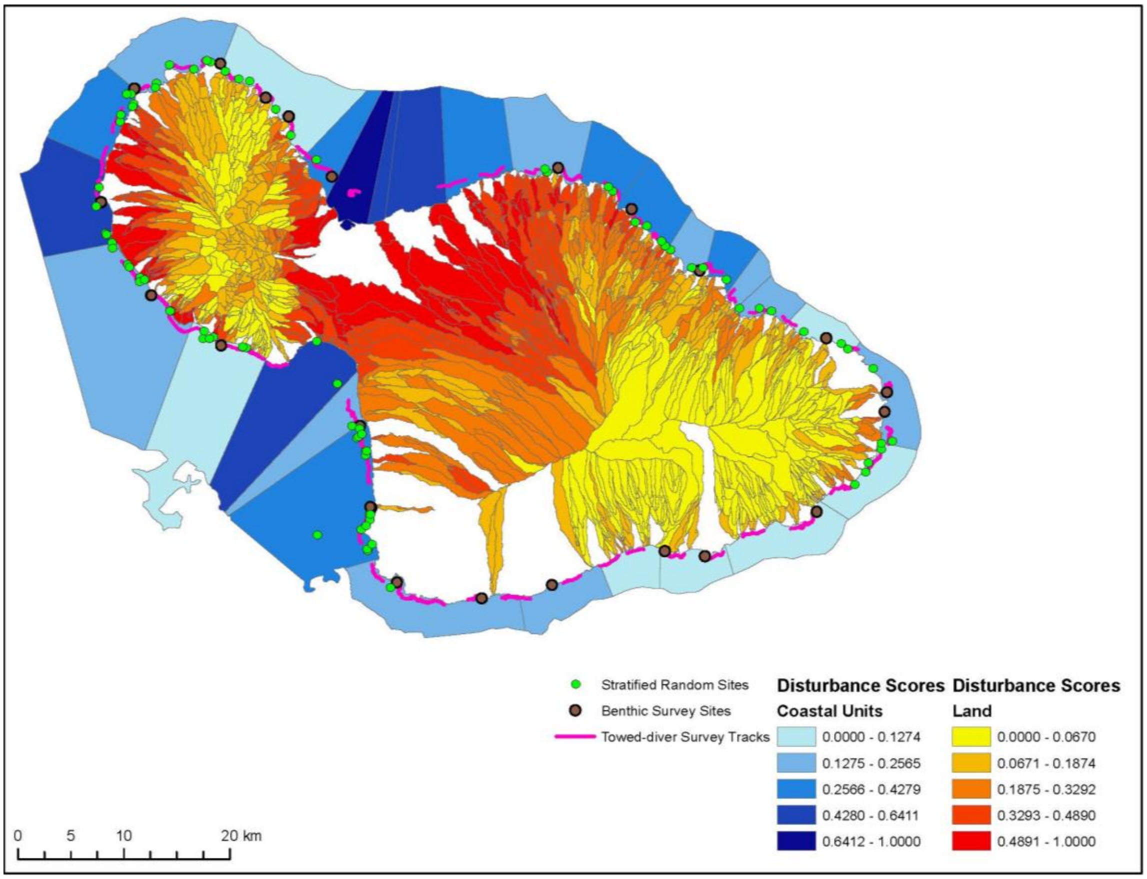

Figure 20. -- Sample Maui map showing NFHP disturbance scores on land (red-yellow); coastal units (blues); and CRED monitoring sites. Map created by Tomoko Acoba.

Sanitation

Data from the Secretariat of the Pacific Community (SPC) also allow us to evaluate the extent to which sewage contributes to coral reef degradation by examining the extent to which residents have access to "improved sanitation" (See Table 11 for the WHO definition of "improved sanitation."). While almost all residents of the U.S. territories have access to improved sanitation facilities, only one-third of the Kiribati population has similar access. Instead, residents use the beach or ocean as their primary place for urination and defecation (Kiribati National Statistics Office, 2007). Table 11 also presents similar data at the island scale for those Kiribati islands in this study. It is useful to note the difference in access to improved sanitation facilities between the more developed island of Kiritimati and the rural, more isolated islands of Kanton, Tabuaeran, and Teraina. Similar data are not available at the island scale for the islands of the U.S. territories.

Table 11. -- Percent of population with access to "improved sanitation facilities."

	% of Population with Access to Improved Sanitation Facility [a]
American Samoa	99 (in 2004)
CNMI	98 (in 2008)
Guam	99 (in 2008)
Kiribati	33 (in 2006)
Kanton	33.3[b]
Kiritimati	63.0 [b]
Tabuaeran	35.8 [b]
Teraina	24.2 [b]

Notes:
[a] According to the WHO, "improved sanitation facilities" are facilities that "hygienically separate human excreta from human, animal and insect contact. Facilities such as sewers or septic tanks, pour-flush latrines and simple pit or ventilated improved pit latrines are assumed to be adequate provided that they are not public" (WHO, 2011).
[b] From Kiribati National Statistics Office 2007.

However, it should also be noted that even though almost all residents of the U.S. territories (and presumably Hawai`i) use improved sanitation facilities, sewage continues to be a problem for coral reefs as a main contributor to point source pollution. For example, although most of the major wastewater treatment plants in Hawai`i discharge to the coastal ocean through deepwater outfalls where there is little potential for impact to coral reefs, spills of untreated or poorly treated wastewater occur frequently. From 2000 to 2004, the City and County of Honolulu reported between 200 and 300 spills per year to the U.S. Environmental Protection Agency (EPA) (Waddell and Clarke, 2008). Although most of these spills were contained on land, many also impact nearshore waters and reefs. Similar problems with sewage spills and untreated wastewater exist in Tutuila and Guam.

Additionally, cesspools contribute to non-point source pollution in Hawai`i. Cesspools are underground holes used throughout Hawai`i for the disposal of human waste. Raw, untreated sewage is discharged directly into the ground, where it can leach out and contaminate ground water, streams, and nearshore environments by releasing disease-causing pathogens and nitrates (U.S. EPA, 2012). Although EPA regulations required that all large capacity cesspools be closed by 2005, more than 1,200 are still in use (States News Service, 2012), and they are more widely used in Hawai`i than any other state. While the extent of nutrient and pathogen seepage from cesspools is not known, they are considered a contributing factor. As such, even having extensive access to improved sanitation does not automatically mean that sewage is not an important contributor to coral reef degradation.

ECONOMIC DEVELOPMENT AND MARINE RESOURCE GOVERNANCE

Economic Indicators

Underlying many of the factors that contribute to coral reef degradation, such as dependence on coral reef finfish and invertebrates for food and the amount of raw sewage being put out in shallow waters, are the economic conditions and level of economic development of island communities. Typically, social science research that examines the relationships between humans and coral reef health (often focusing on the level of reef fish catch or dependence) does so at the community level, collecting economic data at the household or individual level regarding income, job multiplicity, the availability of other employment and income opportunities, and the socioeconomic status of fishermen or those dependent on local resources when compared to the larger community (Brewer et al., 2009; Cinner, 2010; Cinner and McClanahan, 2006). Due to the large amount of variability that exists within a larger geographical area (such as an island, state, or country), it is difficult to develop indicators for these variables without conducting comprehensive field work.

Kronen et al.'s 2010 study compared a set of 63 communities in 17 Pacific island countries and territories in terms of socioeconomic indicators and drivers linked with exploitation levels of finfish and invertebrates of coastal communities. They found that community-level indicators, such as the marketability of resources harvested, explained 34.2 percent of the variation in finfish catch rates, while national-level indicators, such as the consumer price index (CPI) and gross domestic product (GDP) per capita, explained only 7 percent of the variation. Moreover, Kronen et al. (2010) found a close relationship between resource exploitation rates and economic development at the national level and the availability of alternative income opportunities at the community level. Again, this suggests that in order to more fully understand resource use and exploitation, it is important to consider the larger social, economic, and political contexts at different scales (community level, island level, state/territory level, national level) in which resource users exist.

However, in the absence of a comprehensive and representative set of comparative data for each of the islands in this study, Table 12 presents two available economic indicators (GDP and CPI) for each of the island groups. Both of these are economic indicators commonly used by international organizations such as the FAO and SPC to compare countries in terms of overall economic growth and development. Not surprisingly, we see in Table 12 that Hawai`i has the highest GDP per capita, followed by Guam, CNMI, and American Samoa. Kiribati has the lowest GDP per capita, at less than 1000 US dollars.

Figure 21 shows the percent of annual change in the CPI for each of the island groups from 2007 to 2011. The CPI measures changes over time in the general level of prices of consumer goods and services that households acquire, use, or pay for consumption (FAO, 2012). It is often used as an indicator of inflation and the buying power of consumers. While the CPI by itself may not be a suitable direct indicator of coral reef health, it can provide useful information regarding the economic welfare of island residents, which may have implications for resource use.

Table 12. -- GDP and CPI for study areas.

	GDP per Capita (USD)	CPI (Annual Percent Change)				
		2007	2008	2009	2010	2011
American Samoa	8,448 (2007)	3.7	10.2	3.3	4.8 [d]	8.1 [d]
CNMI	15,006 (2007)	6.9	4.8	2.1	1.4 [e]	0.6 [e]
Guam	24,827 (2007)	6.8	4.3	1.7	2.9 [c]	3.3 [c]
Hawai`i [a]	48,553 (2007)	4.8	4.3	0.5	2.1	3.7
Kiribati	947 (2008) [b]	4.1	10.8	8.8	-2.8	1.2

Notes: All data from SPC (2010) unless otherwise noted:
[a] State of Hawai`i (2011)
[b] ADB (2009)
[c] Guam Bureau of Statistics and Plans (2012)
[d] American Samoa Department of Commerce (2012)
[e] CNMI Government Department of Commerce (2012)

For example, we notice a 10.2 percent increase in CPI in 2008 in American Samoa, which is relatively high when compared with the other U.S. states and territories in this study for that year. A typical assumption is that as the price of goods increases in small island communities, individuals may increasingly turn to subsistence catch of fish instead of buying food. The increase in subsistence catch of reef fish and invertebrates may, therefore, have a negative impact on fish populations and the coral reef ecosystem in general.

However, if we further examine what else was occurring around that time period in American Samoa, we see that beginning in 2007 and per U.S. Congressional mandate, American Samoa began increasing the minimum wage of its workers. The U.S. Government Accountability Office (GAO) found in 2010 that although the CPI increased by 10.2 percent in 2008, the minimum wage for many workers actually increased by a larger percent (31 percent). Further, although minimum wage increases are often expected to increase consumer prices (Nguyen, 2011), because 90 percent of the American Samoa economy is dependent on foreign and U.S. imports, the increase in local prices experienced in American Samoa from 2006 to 2008 largely resulted from rising prices of imported goods such as food, utilities, and transportation (U.S. GAO, 2010). Additionally, it may be important to consider the cultural aspects of an island's residents when looking for relationships between economic conditions and the health of coral reef ecosystems, perhaps mediated by reef fish catch (as described earlier). For example, because the dependence on reef fish for food is relatively low in American Samoa, as economic and social conditions have altered residents' preferences toward store-bought foods over the past few decades, it is not likely that a large increase in the price of goods would lead to a large increase in subsistence fishing pressure (Sabater and Carroll, 2009). In summary, although an examination of CPI and GDP trends may yield anomalies that warrant further research, using those trends as a simple proxy for impacts on reef health can be misleading.

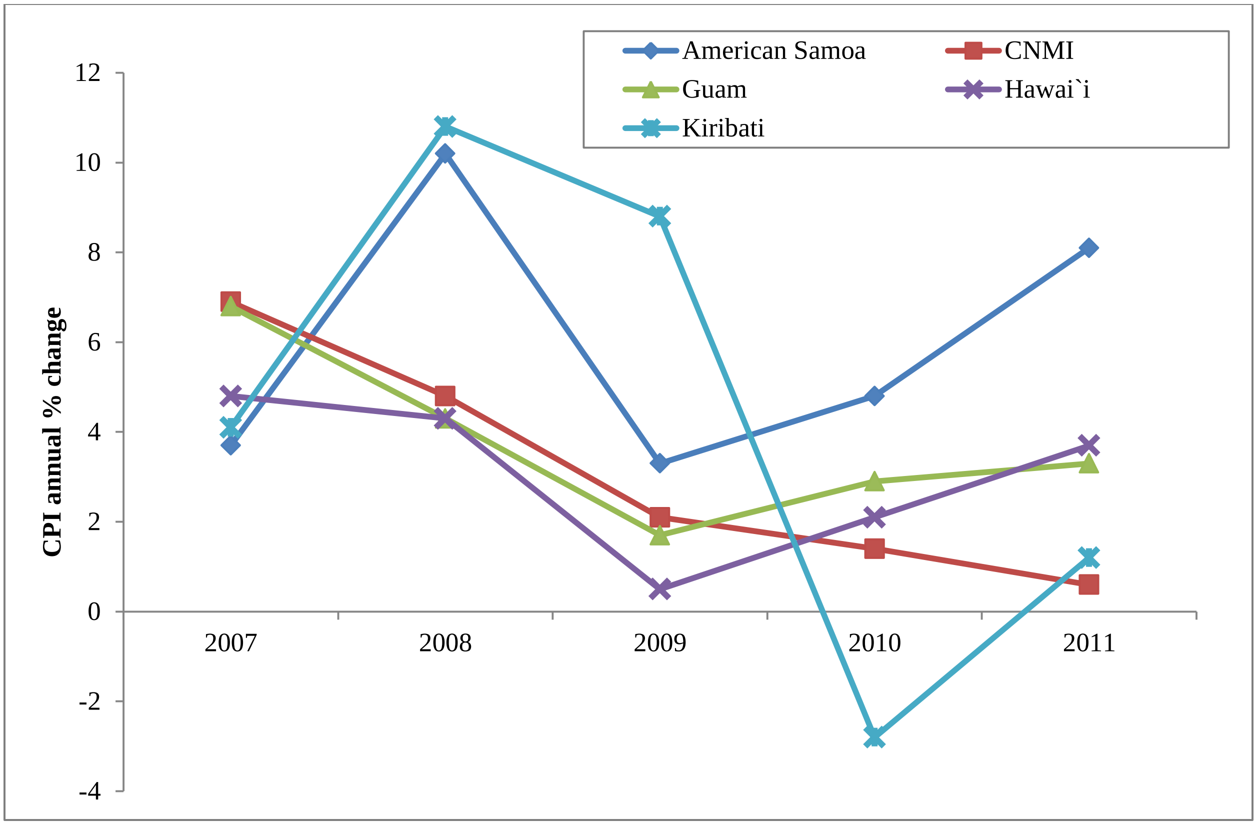

Figure 21. -- Percent of annual change in the CPI for each of the island groups from 2007 to 2011.

Governance

Environmental governance can be defined as "the formal and informal arrangements, institutions, and mores which determine how resources or an environment are utilized; how problems and opportunities are evaluated and analyzed; what behavior is deemed acceptable or forbidden; and what rules and sanctions are applied to affect the pattern of resource and environmental use" (Juda, 1999, pp. 90-91). It is difficult, however, to "measure" governance, nor can one type of institutional arrangement be deemed "better" than others or be given a higher "score." For many different types of governance arrangements, there are examples throughout the world in which management goals were successfully achieved, as well as those in which goals were not achieved.

Nonetheless, governance is important to consider when examining the relationships between humans and coral reefs because those relationships can be impacted by factors such as the type of management system in place, the extent to which resource users accept and follow management strategies, and the manner in which resource users perceive coral reefs as a resource to be owned, used, or preserved. Generally, management tools are more likely to be accepted if they build on local views and beliefs (Kronen, 2010; McClanahan et al., 2009), but a variety of other factors impact the extent of acceptance, and even more so the extent of compliance.

Despite the challenges associated with measuring governance, indicators have been developed in attempt to do so, such as the Worldwide Governance Indicators (WGI). The WGI are a set of indicators developed by the World Bank Institute and the Research Department of the World Bank for the purpose of making cross-country comparisons regarding governance. The six indicators include: Voice and Accountability, Political Stability and Absence of Violence/ Terrorism, Government Effectiveness, Regulatory Quality, Rule of Law, and Control of Corruption. They are composite indicators based on several hundred variables obtained from more than 30 different data sources, representing perceptions of governance reported by non-governmental organizations (NGOs), survey respondents, commercial business information providers, and public sector organizations worldwide (Kaufmann et al., 2010). Table 13 presents the WGI data for three of the island groups in the study: American Samoa, Guam, and Kiribati (These data are not available for CNMI or Hawai`i). The WGI provide an estimate of governance for each indicator, ranging from -2.5 (weak) to 2.5 (strong) governance performance. Additionally, each country is given a percentile rank among all countries for which the WGI have data (more than 200 countries and territories), ranging from 0 (lowest) to 100 (highest). Although not shown in Table 13, the upper and lower bounds of a 90 percent confidence interval for the percentile rank are provided in the WGI data set to assist in cross country comparisons, as well as comparisons for a specific country over time. According to Kaufmann et al. (2010), the governance estimates of two countries can be considered statistically significantly different (to the 90% level) if the countries' 90% confidence intervals do not overlap. These cases are indicated in Table 13. Data regarding the number of sources utilized to compute the governance performance estimate are also provided.

From Table 13 we see that Kiribati's governance performance estimates differ significantly from those of American Samoa, Guam, or both, for Government Effectiveness, Regulatory Quality, and Rule of Law. In most cases, the estimates for American Samoa and Guam are very similar or identical.

Figure 22 shows the Government Effectiveness percentile ranks with the 90 percent confidence intervals for Kiribati and American Samoa. Because the confidence intervals do not overlap, we can consider this difference to be statistically significant (Kaufman et al., 2010). Although the WGI are not focused specifically on *environmental* governance, this indicator can be applicable to how natural resources, such as coral reefs, are managed. For example, the WGI developers indicate that the "government effectiveness" indicator "reflects perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies" (Kaufmann et al., 2010, p. 4). Regarding environmental governance, this could be used as an indicator of the quality of policies, laws, and management strategies discussed, proposed, or implemented, the extent to which the government actively supports and enforces those policies or laws, and the extent to which others perceive the government's level of commitment.

Table 13. -- Worldwide Governance Indicators scores for study area.

WGI Indicator	Country/ Territory	2009		2010		2011	
		Est. [a]	Rank [b]	Est. [a]	Rank [b]	Est. [a]	Rank [b]
Voice and Accountability	American Samoa	0.99	77.73	1.02	79.15	1.04	80.75
	Guam	0.99	77.73	0.80	71.56	0.82	72.30
	Kiribati	0.71	68.72	0.71	68.72	0.85	73.71
Political Stability/No Violence	American Samoa	0.96	83.89	0.94	81.13	0.98	80.19
	Guam	0.42	60.66	0.43	60.38	0.84	71.23
	Kiribati	1.44	97.16	1.48	97.64	1.33	96.23
Government Effectiveness	American Samoa	0.49	67.46 *	0.49	66.99 *	0.48	67.77 *
	Guam	-0.03	53.59	-0.03	54.55	-0.03	54.03
	Kiribati	-0.79	23.44 *	-0.85	21.05 *	-0.77	24.17 *
Regulatory Quality	American Samoa	0.39	63.64 *	0.38	63.64 *	0.38	62.09 *
	Guam	0.63	72.25 *	0.63	73.21 *	0.63	72.51 *
	Kiribati	-1.23	8.61 *	-1.35	6.70 *	-1.42	6.64 *
Rule of Law	American Samoa	1.17	86.26 *	1.16	85.31 *	1.14	84.98 *
	Guam	1.17	86.26 *	1.16	85.31 *	1.14	84.98 *
	Kiribati	0.18	60.19 *	0.08	56.87 *	0.08	58.22 *
Control of Corruption	American Samoa	0.38	69.86	0.37	68.42	0.36	68.25
	Guam	0.86	77.51	0.85	77.51	0.83	76.78
	Kiribati	-0.13	55.02	-0.05	56.94	0.13	62.56

Notes: Data from World Bank Group, 2012.
* Governance scores differences found to be statistically significant. Data for CNMI and Hawai`i not available.
[a] Governance performance estimate; range is -2.5 (weakest) to 2.5 (strongest) governance performance.
[b] Percentile rank among all countries in the WGI data set; range is 0 to 100.

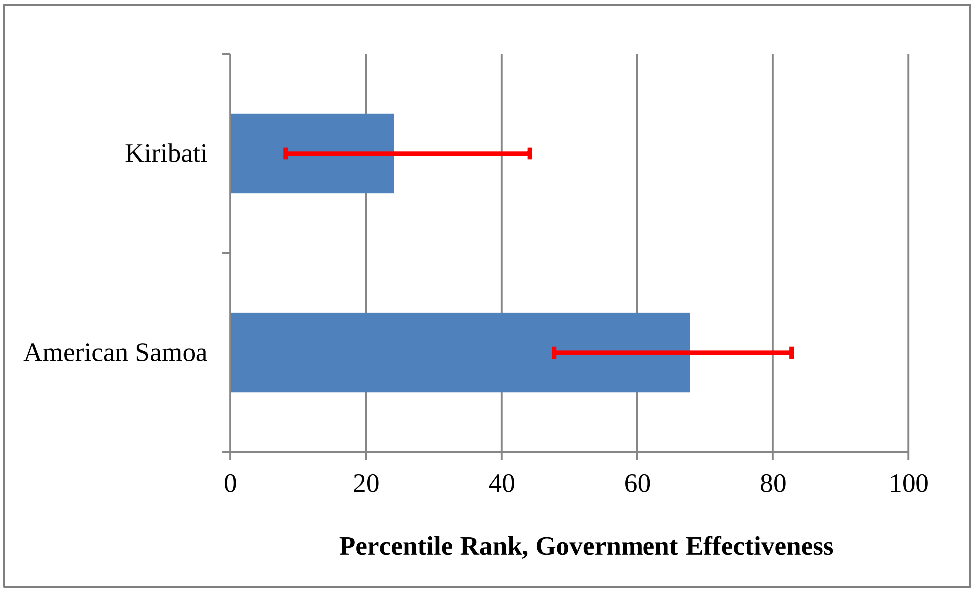

Figure 22. -- Government Effectiveness scores for Kiribati and American Samoa.

If we supplement these Government Effectiveness estimate data with contextual information regarding how coral reef and fisheries resource management occurs in the Kiribati and American Samoa islands included in this study, then these data may be useful. For example, governance in the Kiribati Line and Phoenix Islands (such as Tabaueran, Teraina, Kanton, and Kiritimati in this study) is limited by the lack of local government bodies and institutions to make decisions in the absence of central authority, which is located hundreds of miles away in South Tarawa in the Gilbert Island group. Although legislation has given local councils authority in theory, the Kiribati central government has been reluctant to provide them with the tools needed to act (ADB, 2009; WHO, 2011). As a result, the Asian Development Bank (ADB) described environmental management and the protection of natural resources as being "virtually nonexistent" in Kiritimati (ADB, 2009, p. 142). One issue impacting the atoll's lagoon and nearshore areas is the increasing bonefishing that is occurring, despite the existence of several areas closed to fishing. Recent efforts to develop Kiritimati have focused on increasing tourism to the island, which is currently primarily dependent on the bonefish sport fishery. However, the increasing population in Kiritimati has also led to large increases in the bonefish fishery by residents for food, and the Fisheries Division (6 employees) has been unable or unwilling to enforce the fishing closures (ADB, 2007; 2009).

In American Samoa, environmental governance in terms of MPAs and fishing closures occurs in several different ways. While there are some areas that are closed to fishing or have limited access developed through a top-down management structure, such as the recent expansion of the Fagatele Bay National Marine Sanctuary to incorporate several new areas and become the National Marine Sanctuary of American Samoa, other management areas have been developed through the American Samoa Government's Community-Based Fisheries Management Program (CFMP). Village-based management systems are still practiced in American Samoa, and villages control rights of access to nearshore marine resources. Each village, then, is able to establish its own restrictions on fishing and shoreline access for the entire community. Although the strength of the management and enforcement of access to marine resources varies between villages, several villages have formalized their management strategies through a co-management partnership with the Department of Marine and Wildlife Resources (DMWR) through the CFMP. Because the MPAs established in this manner are managed by local communities that have a vested interest in their success, compliance with fishing regulations is relatively high (Richmond and Levine 2012).

Although the Government Effectiveness indicator is not focused solely on environmental governance, these short case studies provide us with an example of how the indicator can be interpreted in terms of coral reef management issues. Although both American Samoa and Kiribati are perceived to have limited resources and capacity with which to manage marine resources, the separation of Kiritimati from the central government and the limited authority attributed to the local government contribute to continued poaching of bonefish and a lack of effectiveness of the MPAs. In American Samoa, the MPAs have generally been successful in that the co-management system has allowed the responsibility for management (and in many cases enforcement) to be placed in the hands of the village communities, contributing to increased local buy-in and compliance.

The point must be made, however, that the Government Effectiveness indicator was not developed to measure coral reef and fisheries governance specifically, and it is not clear the extent to which environmental governance issues were taken into consideration in the development of the WGI. Further, it must be noted that for the WGI for the U.S. territories of American Samoa and Guam, the governance estimates were made based on only 1 data source, as opposed to Kiribati, the scores for which are an aggregate of 4 data sources on average, or an average of 7 data sources for the data set in its entirety. This means the governance indicators for the U.S. territories could be biased based on that 1 data source. These examples are only included to demonstrate how the WGI data *could* be integrated with qualitative and descriptive data in order to better understand environmental governance in a particular island group.

CONCLUSIONS

This report examined the potential of using secondary human and social data to better understand the complexities of human-reef relationships across 70 island, reefs, and atolls in the Pacific Islands region. Four main aspects were evaluated: 1) population and demographics, 2) reef fishing pressure, 3) land and watershed alterations, and 4) economic development and marine resource governance. In each section, the report describes the data available on each topic, compared the study sites (or a subset of study sites) using those data, and discussed the utility of those comparisons by drawing on qualitative and other site-specific supplemental data. The analysis found that, though these data were somewhat useful in characterizing human-reef relationships and the potential for anthropogenic impacts on reefs, these indicators are impaired by the lack of available, comparative data at a sufficiently fine scale to enable meaningful comparisons.

Discussion and Caveats

The 70 islands, reefs, and atolls in this study occur across a wide range of social conditions with varying degrees of potential anthropogenic impacts on local coral reefs. As the data presented here show, they exhibit a great deal of variation regarding size of human population, extent of land development, and reliance of residents on reef fishing for economic and sociocultural purposes. While the great deal of variation across islands is part of what allows for potentially interesting comparisons, it also creates challenges for the development of human dimensions indicators from secondary data sources that are representative of both local conditions as well as those present across the entire gradient of islands. This analysis highlights the fact that the social data available for this region are often not only scarce, but also inconsistent across archipelagos and even between islands in the same archipelago or island group.

For example, the differing political scales of the islands in the study contributed to the paucity of social data. While certain data sets contained information for each island of the State of Hawai`i, these often did not have comparable data for the islands of each of the U.S. territories (Guam, CNMI, and American Samoa) at the same scale. Moreover, the data available for Kiribati were often at the national scale. In some cases, national scale data can be used for island-scale comparisons by assigning each island the same value as provided at the national level. This is especially problematic for Kiribati, however, because more than 90 percent of the country's population lives in the Gilbert Island group, which is not included in the study sites (Kiribati National Statistics Office, 2007). Further, half of the population in the Gilbert group lives on South Tarawa, which has extremely high population density and suffers from many of the common public health and infrastructure issues faced by other urban areas throughout the developing world. As a result of these population patterns, most of the national level statistics for Kiribati are more representative of conditions experienced in the urban areas of the Gilbert group, not of those experienced in the Kiribati islands in this study in the Line and Phoenix Islands. A similar case is found regarding national level data sets for the United States. For example, it is not appropriate to use data representing the United States as a nation, such as economic indicators like the per capita gross domestic product (GDP), to represent economic conditions experienced in the U.S. territories, where economies are much less developed and growth is more difficult.

Much of the social science research that has been conducted in the study islands have been in-depth studies of particular sites and/or communities, producing data relative to specific topics (Allen and Amesbury, 2012; Allen and Bartram, 2008; Glazier, 2007; Herdrich and Armstrong, 2008; Kittinger et al., 2011; Levine and Allen, 2009; Richmond and Levine, 2012). While these data are informative and useful for many research purposes, it is rare to find complementary data across all the islands that allows for the kind of large-scale comparative analysis presented here.

Moreover, the need for human dimensions indicators that allow for island-scale comparisons is problematic in regards to the meaningfulness of the indicators. While it is certainly possible to use the available case study, site-specific data to qualitatively develop an island-scale indicator (e.g., a cardinal ranking of 1–5) of, as described in this report, residents' dependence on reef fish, it is difficult to say what utility such a measure has for describing the variation that exists across the islands and, most importantly, across multiple communities or villages within a specific island. For example, in the case of dependence on reef fish, multiple types of dependence can be characterized (e.g., economic dependence, nutritional dependence, cultural dependence) and each type may have variable impacts on coral reef ecosystems. Additionally, because *intra*-island variation across communities can often be as great or greater than the *inter*-island variation perceived among islands, an island-scale indicator does not capture much of the variation across study sites. As such, smaller scale indicators may allow for a better understanding of the motivations behind the use of reef resources at the local scale. This, in turn, will allow for the development of more effective and culturally-sensitive coral reef ecosystem management strategies.

Future Research

The larger research project of which this is a part ("Comparative Analyses of Natural and Human Influences on Coral Reef Community Structure, Diversity, and Resilience") utilizes the unique gradient of ecological conditions found in the Pacific Islands to make island-scale comparisons. At this time, the only social data that are available for all of the study locations are population and demographic data. However, as was shown here, these data have limited ability to uniformly describe the relationships of humans with reefs and other marine resources and/or the impacts of humans on reef ecosystems. Each community is a unique combination of a variety of demographic, economic, social, and political factors that contribute to how marine environments are valued and used by community members. Further, just as physical scientists have realized that several factors may interact to affect coral reef ecosystems in a unique way in a particular place, or that a particular factor may affect different facets of the ecosystem in different ways, the same is true for social systems. Future research should focus on identifying how social and ecological factors affect one another at various scales and how they can be integrated into complex social-ecological systems. Additionally, it is important to explore these social-ecological systems viewing humans as a neutral component of the system that also improves the condition of resources, instead of only viewing humans in terms of their negative impacts on coral reef ecosystems (Kittinger et al., 2012). Several social scientists are moving toward this approach, analyzing relationships between humans and reefs in terms of the goods and services they provide to communities and how those impact human well-being (Daw et al., 2011; Pollnac et al., 2006).

To conduct the island-scale analyses proposed by the larger study in a comprehensive and appropriate manner, a large amount of time and money would need to be put toward collecting a uniform set of social data from all study locations to allow for meaningful comparisons. For a variety of factors, including the isolated nature of the island groups from one another and the likely continued decrease of government funding for this kind of research, one would not expect such a data set to be completed in the near future.

Therefore, researchers must continue to work at smaller scales to integrate ecological and social data, but also emphasize the need for those working in different locations to coordinate and find ways to collect data that will allow for comparisons at larger scales. The need for these types of coordinating networks is being increasingly realized, and several such efforts have been initiated, especially in reference to small-scale fisheries, including many that occur in small island communities (e.g., Small-scale and Artisanal Fisheries Research Network, Too-Big-to-Ignore

Global Partnership for Small-scale Fisheries Research). Utilizing these kinds of networks and coordinating communication among researchers may be a more economic and realistic way to move towards having the ability to conduct large-scale analyses of social-ecological systems, without having to sacrifice the rich and comprehensive data typically generated by in-depth, community-based social science studies.

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