

# Development of Indicators for Measuring Effects of Human Activities on U.S. Pacific Coral Reefs

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**Abstract.** 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, ranging from fishing and land development to anthropogenic climate change, and current research has begun to examine the intricacies of the relationships between anthropogenic factors and coral reef health. This paper describes current research to develop human dimensions data that can be synthesized with coral reef biophysical data to measure human impacts on coral reefs throughout the U.S. Pacific. Some of the challenges inherent in this research are how to characterize and compare coral reef fisheries across the region using the small amount of available fisheries data while taking into consideration the larger social, political, and historical context in which these fisheries are embedded. While it is important to understand the overarching trends and commonalities across coral reef fisheries so that management strategies can address conservation concerns in a consistent manner, we need to be able to advise managers on ways to incorporate knowledge of local human interactions with coral reef ecosystems and involve the institutions that manage them at a local scale.

**Key words:** Human dimensions, anthropogenic impacts, Reef fisheries, Pacific, Comparative.

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## 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. 2011; Williams, et al. 2008). 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 coral disease and human population size (Aeby, et al. 2011a). These studies are extremely important because coral reefs provide critical resources to millions of people throughout the world (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 region, including the Hawaiian Islands, the Line Islands, and several other US-affiliated islands (e.g., Commonwealth of the Northern Mariana Islands, CNMI; Guam, 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. 2011; Williams, et al. 2008), coral disease (Aeby, et al. 2011a; Aeby, et al. 2011b), and overall reef community structure (Sandin, et al. 2008). Several of these studies have examined the variation in ecological components in terms of human population or population density, using those data as proxies for an overall level of anthropogenic impact.

As part of an ongoing collaboration between the Coral Reef Ecosystem Division (CRED) and the Human Dimensions Research Program at the NOAA Fisheries’ Pacific Islands Fisheries Science Center, and the Scripps Institution of Oceanography’s Center for Marine Biodiversity and Conservation, researchers are moving beyond using human population size as a proxy for human impacts toward a more in-depth examination of human-reef relationships. A diverse array of information on human activities and other social data are being compiled to be analyzed in

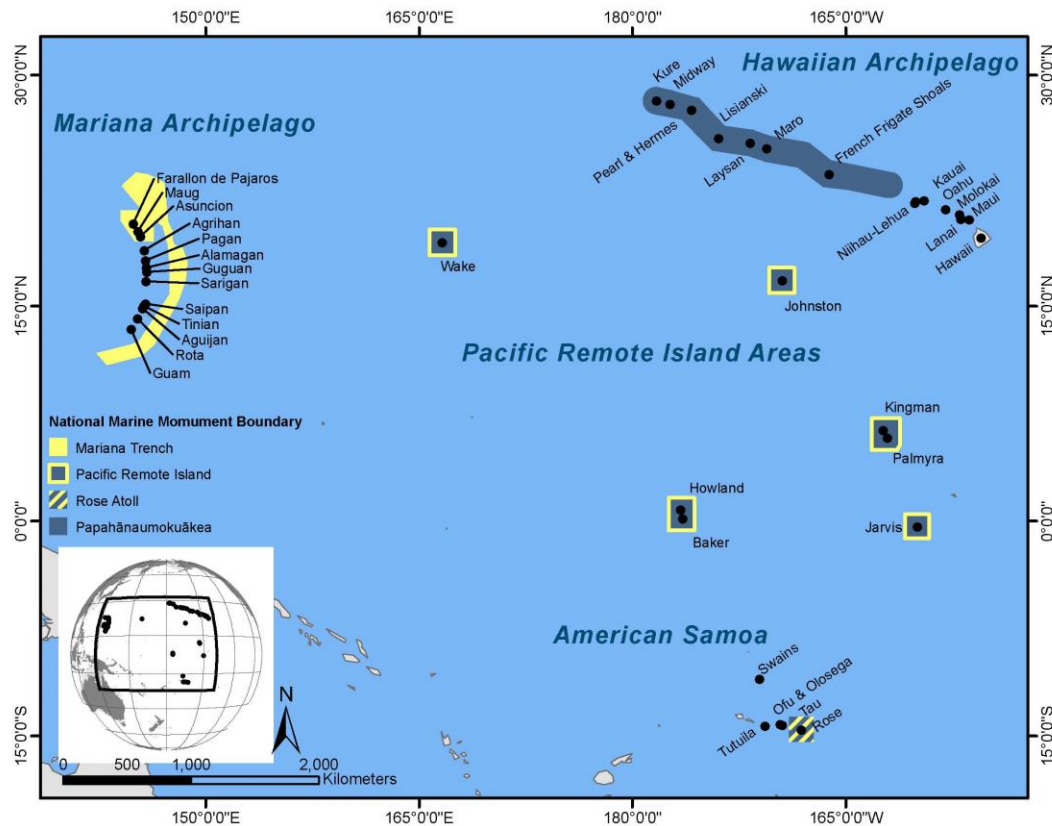


Figure 1: Locations of the islands and atolls included in this study. Map used with permission from Williams et al. 2011.

conjunction with biophysical coral reef ecosystem data collected through CRED's Pacific Reef Assessment and Monitoring Program since 2000. This paper focuses on the strategies being used to develop a set of human dimensions indicators from the existing data currently available. This will allow for comparison of human uses and anthropogenic effects across the reefs and atolls being studied at the island scale. Some of the challenges inherent in this research are to characterize and compare coral reef fisheries across the region using the small amount of available fisheries data while taking into consideration the larger social, political, and historical context in which these fisheries are embedded. Thus while it is important to understand the overarching trends and commonalities across coral reef fisheries so that management strategies can address conservation concerns in a consistent manner, we need to be able to advise managers on ways to incorporate knowledge of local human interactions with coral reef ecosystems and involve the institutions that manage them at a local scale.

### Material and Methods

The locations included in this study are the coral reefs and atolls of the Hawaiian Archipelago, Mariana Archipelago, American Samoa, and the Pacific Remote Island Areas (PRIAs, such as Johnston and Wake Atolls) (Fig. 1). These islands and atolls occur across a wide geographical range and their coral reefs are exposed to varying degrees of potential anthropogenic impacts. For example, 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 socio-cultural purposes. A broad-scale, comparative research approach can provide important information regarding the complex relationships between and among the ecological and human dimensions variables, and how they interact to impact coral reef health. Further, the analyses of these data may allow for important patterns to emerge among these factors that are not apparent from the small-scale, case study approach with which social scientists typically examine social-ecological systems.

While the variation across islands is part of what allows for potentially interesting comparisons, it also

creates challenges for the development of human dimensions indicators from existing data sources that are representative of both local conditions and those present across the entire gradient of islands. Without first-hand data collection, researchers must rely on the social data available for this region—data that are often not only scarce, but inconsistent across archipelagos and even between islands in the same archipelago. Much of the social science research that has been conducted in the US Pacific region has involved in-depth studies of particular sites and/or communities, producing data relative to specific topics. While these data are informative and useful for many research purposes, it is rare to find complementary data across all the islands that allow for comparison.

Moreover, it may be difficult to find human dimensions indicators that allow for meaningful island-scale comparisons. While it is certainly possible to use site-specific case study data to qualitatively develop an island-scale indicator (e.g., 1-5) of, for example, residents' dependence on reef fish, it is difficult to say what utility such a measure would have 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, there are multiple types of dependence that can be characterized (e.g., economic dependence, nutritional dependence, cultural dependence) and which may have variable impacts on coral reef ecosystems. For this reason, it is important to understand the motivations behind the use of reef resources at the local scale, so that effective and culturally-sensitive management strategies can be developed and implemented.

### **Developing Indicators**

After months of collecting and collating existing data regarding human uses of and impacts on coral reef ecosystems throughout the US Pacific region, we have developed a set of potential human dimensions indicators that will be used to characterize the islands in the study. Several categories of indicators were developed, as follows:

#### *Population and Demographics*

This set of indicators will compare the islands in the study in terms of current population, population change, and other demographic variables such as ethnicity and education level of residents. Indicators for this group may include:

- Current population
- Population change since 2000 (when bio-physical data collection began)

- Population change since 1970 (first year US census data is available for all islands)
- Population density (per land area)
- Population density (per reef area)
- Tourist population (visitors per year)
- Educational attainment (e.g., high school, university)
- Ethnicity (e.g., percent of population that is native-born)

Comparing the islands on these factors will allow for the examination of the relationship between human population, population growth, or population density and aspects of coral reef health (as determined by the project's ecologists). It is important to include a factor for tourist population when studying islands in the US Pacific because for some islands, the tourist population (visitors per year) is quite large relative to the resident population. For example, in 2010, the island of Maui had close to 2.1 million visitors, yet the resident population for that year (determined by the 2010 US Census) was only about 144,000 people (Hawaii Tourism Authority 2010; US Census Bureau 2011). Additionally, it is important to include certain demographic characteristics, such as the percent of the resident population that is native-born, as some studies have shown that non-native, migrant resource users may use resources in less conservative ways (Chuenpagdee and Jentoft 2007; Pomeroy, et al. 2007).

#### *Fishing Pressure*

This set of indicators will compare the islands in terms of the level of fishing pressure exerted on the local reef fisheries. Some of the potential indicators for this group include:

- Total catch of reef fish
- Level of dependence on reef fish (e.g., for food, cultural purposes)
- Characterization of artisanal fleet (e.g., number of boats, average size of boats)
- Most common gear used

For some of the uninhabited, isolated islands in the study such as Jarvis Island, the reef fishing pressure is very low (perhaps very rarely fished by illegal fishers) if not non-existent. For the other more populated islands, such as Oahu or Saipan, however, it is much more difficult to determine the total catch of reef fish per year because a large percentage of that catch occurs by recreational and subsistence fishers, who are not required to report their catch. Although creel surveys are currently conducted on the most populated island of each of the US territories (Saipan, CNMI; Guam; Tutuila, American Samoa), much of the reef fish catch is not accounted for due to the voluntary nature of the surveys and the blurring between

recreational, subsistence, and commercial fishing that currently exists in these locations. Additionally, these surveys are not conducted on less-populated islands (such as the Manu'a islands in American Samoa), where residents' dependence on reef fish for subsistence, and therefore catch of reef fish, may be greater than on the populated islands.

In the absence of comprehensive and reliable reef fish catch data, comparing the islands in the study on fishing pressure will entail the development of a scale (such as 1 to 5) based on other social data. These include data that characterize the artisanal or small-scale fleets (such as number of boats, average size of boats, and the most common gear used), as well as data which indicate the level of island residents' dependence on reef fish for nutrition or cultural purposes.

#### *Land and Watershed Alterations*

This set of indicators will compare the islands in terms of the extent of land and watershed alterations exhibited, which have the potential to influence reef health. Some of the potential indicators in this group include:

- Degree of urbanization
- Amount of cultivated land
- Anthropogenic nutrient run-off
- Run-off hazard index
- Land devoted to livestock
- Type of waste treatment

These data are important to include because the sediment, nutrients, and other pollutant runoff can greatly impact nearshore water and reef ecosystem conditions. There is great variability in the extent of land alterations across the islands, as these impacts will be much higher on more developed islands such as Oahu, due to greater urbanization and the large presence of golf courses and tourism-related resorts. Additionally, it is important to include a metric related to the run-off hazard of watersheds (based on slope, land use, erodibility, and rainfall) because several of the islands have mountain ranges with very abrupt changes in elevation, such as Ta'u in American Samoa, and volcanoes, such as Agrihan in CNMI.

#### *Social Capacity*

This set of indicators will measure the extent to which each island's society and institutions are able to effectively manage marine resources. Potential metrics include:

- Average wealth and wealth distribution of residents
- Government capacity to develop, implement, and enforce rules

- Strength of customary and other management practices
- Economic diversity (e.g., dependence on tourism or other industries, impact of military presence)

Again, there is great variability across the islands in terms of this group of indicators, and an overall lack of consistent data available. These indicators are important to include because they provide important information regarding the underlying social and economic factors that impact the types of strategies used to manage resources, as well as the ability of governments and institutions to effectively implement and enforce those strategies. Additionally, they take into account the ways in which social institutions can function to help conserve and ensure the long-term sustainability of marine resources through more formal management mechanisms such as marine protected areas, as well as more informal customary marine tenure regimes.

#### *Military Impacts*

To compare the islands in terms of the potential environmental effects on reefs of military activities occurring on or near them, a scale (or set of scales) will be developed by a military researcher using archival research methods. This scale will be based on the impacts of various military activities since 1900, and may include:

- Number of people present (military and civilian), both long-term as well as short-term
- Infrastructure built (temporary or permanent barracks, runways, etc.)
- Alterations made to the islands, such as areas dredged to allow boat and ship access, or dredging coral and using it to expand the size of the islands
- Battles fought on or near the islands—type of battle, airplane crashes, ships grounded or sunk
- Military materials left behind when the islands were vacated—explosives, ordinances, or other materials or weaponry
- Military exercises (e.g., nuclear testing) practiced on or near the islands

This metric will allow for comparison between islands with high levels of military activities historically (such as Midway Atoll), recently (such as Oahu and Guam), and those with little or no impact from military activities (such as Asuncion, CNMI).

#### **Discussion**

Once the human dimensions indicators are developed, they can then be analyzed alongside the biophysical ecological data derived from CRED's coral reef surveys. These analyses will allow us to better understand the relationships between people and the reef resources upon which they depend. Further, they

will allow us to examine how several human activities and social variables might interact with one another, as well as ecological factors, to promote or degrade coral reef health.

The current effort to develop island-scale human dimensions variables for the US-affiliated Pacific islands has highlighted the need for consistent and comparable social data. While we expect that this island-scale comparative effort will allow us to uncover interesting broad stroke relationships between the ecological and human dimensions factors, it is impeded by the lack of available secondary data. If this type of research is to be continued in the future, we highlight the need for long-term island-scale human dimensions monitoring so that we will have meaningful, appropriate, and consistent social data with which to compare all islands.

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