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Small-Scale Fisheries : : from a Broad Overview to a Case Study

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Small-Scale Fisheries: from a Broad Overview to a Case Study

A Thesis submitted in partial satisfaction of the requirements
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in

Biology

by

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2014

The Thesis of Cristiane Palaretti Bernardo is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

Co-Chair

Chair

University of California, San Diego

2014

DEDICATION

I dedicate this thesis to the people of Tonga, who gave me much more than what I could expect.

EPIGRAPH

For small creatures such as we the vastness is bearable only through love.
Carl Sagan

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ABSTRACT OF THE THESIS

Small Scale Fisheries: From a Broad Overview to a Case Study

by

Cristiane Palaretti Bernardo

Master of Science in Biology

University of California, San Diego, 2014

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At least half of the world's food fish supply comes from small-scale fisheries. In many island countries, almost everyone relies on small-scale fisheries as a source of protein, income, livelihood, and cultural tradition. Here, we investigate the changes in the actual production of small-scale fisheries across 48 tropical islands over a period of 10 years and examine socioeconomic factors as possible reasons for changes in fisheries production over time. Our results indicate that the majority of the countries with overexploited fisheries status had increased in production contradicting the maximum

sustainable yield (MSY) theory, which state that an overexploited fisheries will over time be collapsed. Many case studies have found relationships between socioeconomic factors and the change in small-scale fisheries production; here, we apply these factors on a worldwide scale. We found no correlation among fisheries production and variables such as population growth, economic growth and governance performance. Even though there is some similarity across small-scale fisheries in different locations, the relationships between humans and fisheries are complex and need to be evaluated locally. The second chapter, a case study, reaffirms that small-scale fisheries can't be generalized and thus need to be study in regionally, as investigations using broad overview of small scale fisheries usually misses very important factors that affects small –scale fisheries production.

Chapter I

Comparative investigation of small-scale fisheries status from 48 tropical coral reef islands over a 10-year period

Abstract

At least half of the world's food fish supply comes from small-scale fisheries. In many island countries, almost everyone relies on small-scale fisheries as a source of protein, income and livelihood, and cultural tradition. Consequently, these fisheries have a direct effect in the community. Here, we investigate the changes in the actual production of small-scale fisheries across 48 tropical islands over a period of 10 years and examine socioeconomic factors as possible reasons for changes in fisheries production over time. Our results indicate that the majority of the countries with overexploited fisheries status had increased in production contradicting the maximum sustainable yield (MSY) theory, which state that an overexploited fisheries will over time be collapsed. For instance, Bahrain, Dominica, and Reunion fisheries went from overexploited to fully exploited; and Comoros, Grenada, and the US Virgin Islands fisheries went from collapsed to overexploited. Many case studies have found relationships between socioeconomic factors and the change in small-scale fisheries production; here, we apply these factors on a worldwide scale. We found no correlation among fisheries production and variables such as population growth, economic growth and governance performance. Even though there is some similarity across small-scale fisheries in different locations, the relationships between humans and fisheries are complex and need to be evaluated locall

I.1 **Introduction**

Small-scale fisheries (SSF) occur throughout the world but are predominantly in tropical, undeveloped countries, where the surrounding coral reefs have high biodiversity [3-5]. At least half of the world's supply of food fish comes from SSF, and it has been estimated that 90% of fishers worldwide are involved in this type of fishery [5, 6]. It is estimated that there are 1.2 million artisanal fishers in the Caribbean and America, 0.98 million small-scale fishers in Africa, and 6.1 million in Asia. All these fishers catch an estimated 6.9 million tons of fish per year [7, 8].

For those living in coastal communities, small-scale fisheries are essential for livelihood, income, and food security [3, 5]. Dependency on fish consumption varies from one country to another; for example, the annual consumption per capita of fish ranges from 14 kg/capita/yr in Vanuatu to 40 kg/capita/yr in Fiji to 69kg/capita/yr in the Solomon Islands. This can be much higher in countries that are farther from developed markets, such as Tuvalu, where up to 1 kg of fish is consumed on a daily basis [9].

For simplicity, in this study small-scale fishing and artisanal fishing are combined. Both terms are used to refer to any fishing on coral reefs that is not sport fishing. It comprises subsistence fishing, meaning harvesting fish as food for fishers and their families, and artisanal, small-scale commercial fishing, on which fish is sold in local market to the community.

Usually coral reef fisheries involve mostly traditional, simple, and without much technical gear. Small-scale fisheries (SSF) are mostly multispecies fisheries. These fisheries count on invertebrates as much as finfish for subsistence; however, finfish is usually more valuable in local markets. In some areas, specially not urbanized, everyone is related somehow to the fishery and thus is affected by the status of the fishery resource. Catches are typically landed in the village or in the fishermen's household [10].

The local villages consume about 80% of the harvested marine resources, and the remainder is sold at local markets [11]. Fishing is carried out mostly by locals, and in addition to providing the bulk of animal protein, fishing supports countless traditional and cultural aspects in these communities. For example, in some areas, is very common to have only women fishing for invertebrates and men for finfish; in other regions, male and female fishers harvest both finfish and invertebrates [12].

Many generations have sustained their livelihoods from coral reef fisheries [13]; however, this relationship, which had seemed to be in equilibrium, has changed since the beginning of the 20th century [14-17]. The recent global pressure on coral reef fisheries comes from multiple human-caused threats related to climate change (causing coral bleaching), pollution, disease, and overfishing [18, 19]. Overfishing is by far the most harmful to the health of coral reef fish communities for some authors [20, 21].

Because fishers generally target large-bodied individuals and species, fishing pressure is known to reduce mean body size and size at first reproduction in fish populations, as well as reduce overall biomass of the fish community (REF) [22]. Moreover, in recent years, traditional subsistence fishing methods have rapidly shifted towards more modern fishing techniques [19], which are often biologically and environmentally unfriendly [17]. This has been aggravated with the increase in local cash economies [16, 18, 23]. For instance, destructive fishing methods – such as the use of explosives, toxic plants, and chemical poisons – have degraded large areas of coral reefs and interrupted complex biological and chemical cycles that support coastal fisheries. Fishing in general, and these selective fishing mechanisms in particular, have therefore changed coral reef fish communities, with unpredictable long-term implications [14].

Estimating the production of small-scale fisheries is extremely important to prevent overexploitation and to prevent those who are dependent on small-scale fishing (and directly related activities) from suffering from lack of resources that are fundamental to their survival [15]. Over the years, there has been an increased interest in understanding factors affecting SSF. The majority of studies, however, are site-specific, most of the time in a very localized area [13, 19, 23-32].

Based on the importance of coral reef fisheries in supporting many coastal communities, Newton et al. (2007) investigated the sustainability of island coral reef fisheries and analyze the fisheries exploitation status of 49 small island nations. Using the sustainable production of coral reef fisheries based in their ecological footprint (Fig. I.1), Newton et al. (2007) classified the countries based on a summary of exploitation status available from varied sources in the literature, presented as underexploited, fully exploited, overexploited, and collapsed. Islands with underexploited fisheries had no indication of fisheries heavy exploitation, fully exploited fisheries had some indication of overexploitation in localized areas only, and overexploited fisheries had clear indication of fisheries impacts based on fish biomass and size. Islands with collapsed fisheries status were the ones with overexploited status in the literature and below the level of predicted sustainability of the fishery (Fig.I.2). Newton et al. (2007) used coral reef fisheries data from 1997 to 2001 with data collated from FAO, Food and Agriculture Organization statistics, for each island. Their results show that 55% of coral reef fisheries from the 49 islands were being exploited unsustainably.

My study builds upon this previous result by addressing the question of how the status of these island coral reef fisheries would change after 10 years. This study has the following two goals: (1) Investigate the change (if any) of the fisheries status of 48 tropical island countries in the 2006-2010 period compared to the 1997-2001 period investigated by Newton et al. (2007); and (2) Determine the relationship between changes in actual fisheries production and socioeconomic factors such as population growth, economic development, and governance indicators. Many studies have

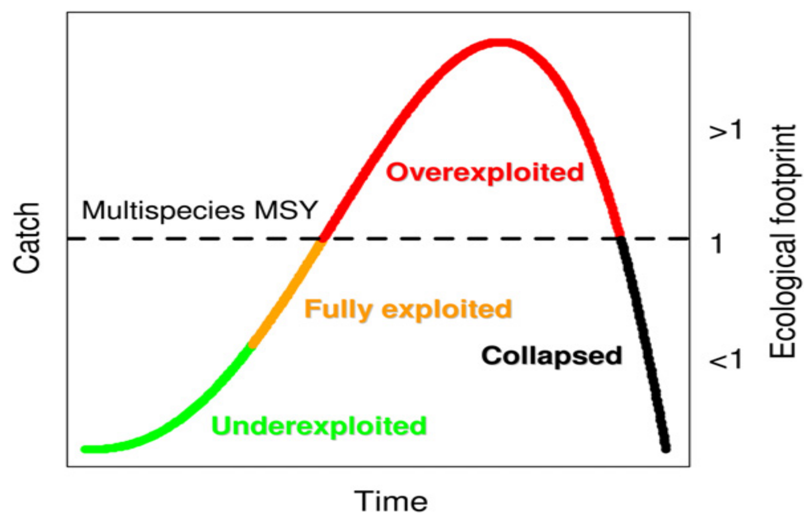

Fig. I.1. The maximum sustainable yield (MSY) curve, which attempts to explain fisheries from underexploited to collapsed. At first, a fishery is underexploited. As the fishery develops exploitation grows exponentially, from fully to overexploited. With continuing exploitation, the fishery eventually reaches a collapsed state. The ecological footprint of the fishery is based on sustainable yield, in which actual reef production is in equilibrium with sustainable reef production. Newton et al. (2007) classified the coral reef fisheries of 49 islands based on this figure.

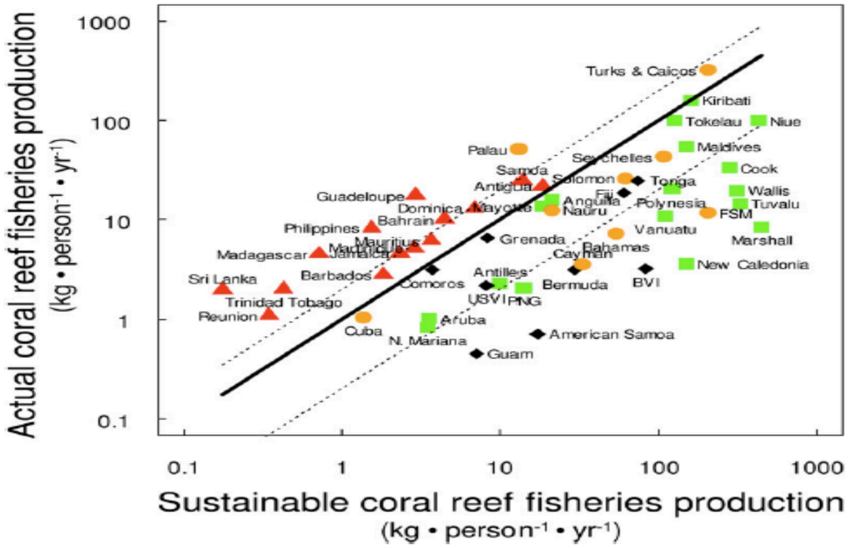

Fig.I.2. Results of Newton et al.'s (2007) classification of 49 tropical island countries according to their fisheries status based on landings data from 1997 to 2001. Black represents countries with collapsed fisheries, red represents countries with overexploited fisheries, yellow represents countries with fully exploited fisheries, and green represents countries with underexploited fisheries. The black bold line represents the sustainable coral reef fisheries production of 5 mt * km^{-2} * yr^{-1} .

investigated the fisheries production according to social, economic and governance factors but they are mostly based in case studies [6, 16, 18, 19, 26]. Here we have the opportunity to analyze these socioeconomic factors in 48 island countries across the tropics with estimates of change over a 10-year time. The goal is to investigate if the socioeconomic factors can be relevant to the change in actual fisheries production in a worldwide perspective.

I.2 Topics of Investigation

I.2.1 Change in actual fisheries production between 1997-2001 and 2006-2010

For the purpose of simplification, the data series from 1997-2001 is hereafter referred to as “time 1” and the data series from 2006-2010 as “time 2.” We have the following expectations of changes in fisheries status based on their status in time period 1:

(1a) If fisheries are collapsed in time period 1, they will be collapsed in time period 2. It would probably be very difficult for a collapsed fishery to fully recover in 10 years.

(1b) If fisheries are overexploited in time period 1, they will be overexploited or even collapsed in time 2. While an overexploited fishery could potentially recover in 10 years, this may be difficult or unlikely over such a short time period.

(1c) If fisheries are fully exploited in time period 1, they will be fully exploited, overexploited, or even collapsed in time period 2. While fisheries could be exploited in a sustainable way; in 10 years a fishery that was previously healthy could change dramatically.

(1d) If fisheries are underexploited in time period 1, they will be underexploited, fully exploited, overexploited, or even collapsed in time period 2. Underexploited fisheries could still be sustainable after 10 years, but they could also easily be exploited unsustainably to the point of collapse.

I.2.2 Socioeconomic factors influencing island coral reef fisheries

The harvesting of natural resources unquestionably is influenced not only by the changes in the environment but also by the socioeconomic factors in a society [16]. Here we will investigate three socioeconomic factors that possibly influence changes in actual fisheries production.

<u>(2a) Population Growth</u>

Assuming that fishing production increases as a response to human population growth in island countries, population growth would have a positive relationship with actual fisheries production over time [18, 26].

(2a) Is population growth a good predictor of the change in actual fisheries production over time across the 48 tropical island countries?

<u>(2b) Economic Growth</u>

The higher the economic growth of a country, the more opportunities people have to pursue other ways of income besides fishing [16]. Also, in island countries the introduction of a Westernized way of living involves the increase of processed food consumption, as opposed to fresh fish [18]. Thus, there might be a positive relationship between economic development and sustainable fisheries production [16]. Assuming that economic growth corresponds to the Gross Domestic Product (GDP) of a country, the higher the GDP of an island country, the less small-scale fishery production will be.

In other words, a wealthier country will have more sustainable fishery production than a less wealthy country (as measured by GDP).

(2b) Is gross domestic product (GDP) a good predictor of actual fisheries production?

(2c) Governance Performance

Fisheries management with realistic community-based policies is the key to conserve fisheries at an ecologically sustainable level, especially when local customary marine tenure (CMT) has eroded. Good governance ensures that policies can be applied to managed to preserve the sustainability of fisheries, making sure that fishers have resources to support future generations while conserving the health of fish communities. Policies such as fishing bans at fish aggregation sites (e.g. grouper aggregation sites in the Cayman Islands [33]), which ensure the species will have time to reproduce before being fished, marine protected areas (MPAs) with take restrictions, no-take reserves (NTRs), and policies against illegal and destructive fishing techniques have been effective in fish population conservation and recovery [33, 34]. Therefore, the better a country's governance in fisheries management, the less exploited that country's fishery should be.

Here we average four governance indicator indexes (government effectiveness, rule of law, corruption index, and regulatory quality) to examine how governance performance and subsequent fisheries policies could be perceived, respected, and enforced.

(1) Government Effectiveness – The government effectiveness index reflects the perceptions of the quality of public services, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies [35]. The higher the government effectiveness index value is, the greater the people's respect

is for the government's fisheries management policies. Fisheries in countries with higher government effectiveness index value should therefore be more sustainable.

(2) Rule of Law – The rule of law index reflects society's confidence in and adherence to laws, particularly the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence [35]. The higher the rule of law index value is, the lesser the fishers' rule-breaking is. For instance, fishers most likely would not fish in a no-take reserve or catch smaller finfish if these activities were prohibited. Fisheries in countries with higher rule of law index values should therefore be more sustainable.

(3) Corruption – The corruption index reflects the perception of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as "capture" of the state by elites and private interests [35]. It is well known that fisheries corruption occurs at the international level, where many rich countries try to bribe fisheries workers of poor countries for access in their Exclusive Economic Zone (EEZ) [36], especially when those countries are not meeting their obligation (e.g. such as whale harvesting). At a national level, management can be corrupt, through statistics and data, at an individual fisher level, corruption can occur through "excess of quotas due to illegal, unreported and unregulated (IUU) fishing," or even smuggling and harassing of observers [36, 37]. Fisheries in countries with lower corruption index values should therefore be more sustainable.

(4) Regulatory Quality – The regulatory quality index reflects the perception of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development [35]. More private sector development means the potential for more non-fishing jobs. Fisheries in countries with higher regulatory quality index values should therefore be more sustainable.

These indexes could be a powerful way to understand changes in actual fisheries production. We expect that countries with high governance performance indicators (good governance performance) will have more sustainable actual fisheries production.

(2c) Is governance performance a good predictor of the change in actual fisheries production over time across the 48 tropical island countries?

I.3 Methods

I.3.1 Change in actual fisheries production between 1997-2001 and 2006-2010

Based on the methods in Newton et al. (2007), the island countries and territories in this study were chosen according to three conditions: (1) presence of coral reefs (defined in [4]), (2) presence of small-scale coral reef fisheries, and (3) availability of both fisheries landings and human population data. From the 49 islands used in Newton et al. (2007), only (former) Netherlands Antilles was not included in the present study, due to the lack of data available after the country became independent from the Kingdom of the Netherlands in 2010 (Fig.I.3).

The average landings of fish, crustaceans, and molluscs for each island were calculated from the Food and Agriculture Organization of the United Nations (FAO) [38] from 2006-2010 and compared with Newton et al. (2007) data from 1997-2001 (Fig.I.2 and I.5). The actual coral reef fisheries production was calculated according to the landings reported in FAO statistics [38] divided by the mean human population [39] and expressed as kg person^{-1} yr^{-1}. Sustainable fisheries production was based on the most current coral reef area [4] and was calculated assuming a maximum sustainable yield (MSY) of 5 mt km^{-2} yr^{-1} [21]. According to maximum sustainable yield (MSY) theory (Fig.I. 1), countries above the sustainable production line were classified as having

SSF Exploitation Status

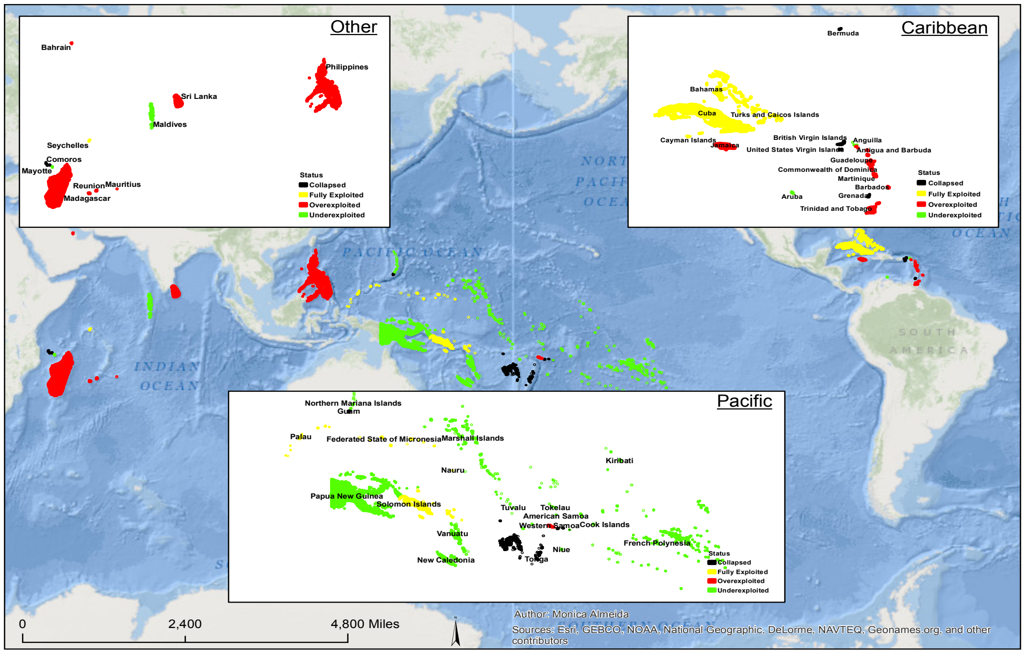

Fig.I.3. The 48 island countries investigated in this study and their actual fisheries production status. We included 17 islands from the Caribbean, 21 islands from the Pacific, and 10 islands from the Indian Ocean, Southeast Asia, and the Middle East. Actual fisheries production status (is indicated by black for collapsed, red for overexploited, yellow for Fully exploited, and green for underexploited fisheries.

Table I.1: Actual fisheries production status (time series 1) and regions.

Region	Collapsed	Overexploited	Fully Exploited	Underexploited
Caribbean	4	7	4	2
Pacific	4	1	4	12
Other	1	6	1	2

* P>Value 0.0063 shows the significance of the Ocean region and exploitation status

overexploited fisheries, countries close to the sustainable production line were classified as fully exploited, and countries below the sustainable production line were classified as underexploited. Lastly, countries below the sustainable production line, but with overexploited fisheries according to the literature, were classified as collapsed (Table I.6).

In Newton et al. (2007) it was used actual fisheries production (landings per capita) as a function of sustainable fisheries production (coral reef MSY and coral reef area per capita) to find the exploitation status of the countries. When considering the change over time (time period [1] and time period [2]) both actual production and the population growth are incorporated. To think about the change in 'sustainability', we have to consider the orthogonal distance to the 1:1 line (line which actual fisheries production equals sustainable fisheries production (Fig. I. 2)). Thus, we created this metric to account for the joint influence of changes in fisheries production and human population size during the intervening period of time. We analyzed the directionality of the change in actual fisheries production from time period 1 to time period 2. For both time periods, we calculated the distance from each country point to the sustainable fisheries line using the Pythagorean theorem formula (Fig.I.4):

$$d = \sin\frac{(\pi)}{4} * \left(\text{Actual Fisheries Production}\,[1] - \text{Sustainable Fisheries Production}\,[1]\right)$$

Then, the change in distance from both time series was calculated. A Student's t-test was used to test for significant differences in actual fisheries production between the two time periods (Fig.I.6).

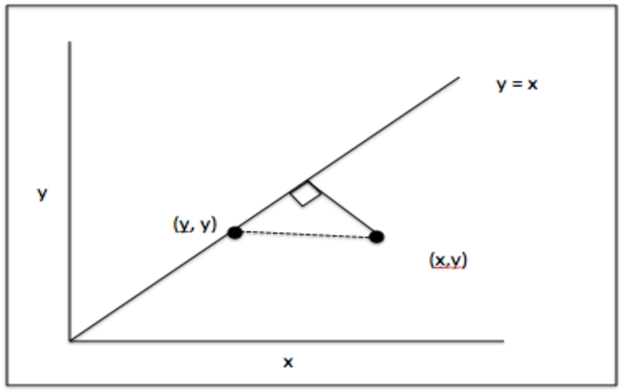

Fig.I. 4. Representation of the calculation to estimate the distance of an actual fisheries production data point from the maximum sustainable yield line.

Supplementary literature studies were also conducted to validate the actual fisheries production status. We used primary and grey literature using a variety of global and regional databases such as Web of Science, ReefBase, and the South Pacific Commission (SPC) library. For each country, we searched articles that clearly estimated the present-day status of coral reef fishery in the area. We used search terms such as “traditional” AND “fisheries,” “subsistence” AND “fisheries,” “island nation” AND “fisheries,” “coral reef” AND “fisheries,” “artisanal fisheries” AND “coral,” and “small-scale” AND “fisheries.” Additional, more specific searches were conducted by adding each of the 48 island nation’s names as a third term in the search. Table I.6 summarizes fisheries status according to the literature research for all 48 countries.

I.3.2 Socioeconomic factors Influencing island coral reef fisheries

In order to investigate factors affecting the change in actual fisheries production, we used three socioeconomic variables. The change in actual fisheries production was calculated as:

$$\left(\frac{\text{Actual Fisheries Production}[2] - \text{Actual Fisheries Production}[1]}{\text{Actual Fisheries Production}[1]}\right) * 100$$

Then, linear regression was used to test for significant relationships between the change in actual fisheries production and (1) the change in human population growth given by [39], (2) economic growth (GDP) taken from [40], and (3) governance performance taken from [35]. These analyses were made in JMP 11 statistical software. Linear regression was conducted for all the 48 islands data series together and also for the 17 islands with the greater change in actual fisheries production and in distance from sustainable fisheries line (Table I.3 - I.4 and Fig.I.7).

Governance performance was calculated by averaging the following indexes: government effectiveness, rule of law, corruption index, and regulatory quality. In total these represent how the performance of the government is perceived as a whole, from a minimum score of -2.5 (very unsatisfactory government performance) to a maximum score of 2.5 (very satisfactory government performance).

I.4 Results

I.4.1 Change in actual fisheries production between 1997-2001 and 2006-2010

In time period 1 (1997-2001), 55% of coral reef fisheries across 49 tropical island nations were classified as unsustainable (defined such that the actual production exceeded the potential production) [41]. After 10 years, however (in time period 2, 2006-2010), only 41.6% of coral reef fisheries across 48 tropical island nations were unsustainable.

(1a) We expected that fisheries classified as collapsed in time period 1 would be collapsed in time period 2. However, our results showed that 67% of collapsed fisheries increased in actual fisheries production. Of the countries with collapsed fisheries in time period 1, Comoros, Grenada, and the US Virgin Islands that were determined collapsed, had overexploited fisheries in time period 2. In both models tested here, the distance from the sustainability model and the actual fisheries production from time period 2, those countries were located above the sustainable line in time period 2 (Fig.I.5 and I.6), indicating that their actual fisheries production have increased.

(1b) We expected that fisheries classified as overexploited in time period 1 would be overexploited or collapsed in time period 2. However, our results showed that 42.9% of overexploited fisheries increased in actual fisheries production. Of the countries with overexploited fisheries in time period 1, Reunion, Bahrain, and Dominica had fully exploited fisheries in time period 2 which suggest that even though their fisheries increased in actual production, their exploitation became more sustainable.

(1c) We expected that fisheries classified as fully exploited in time period 1 would be fully exploited, overexploited, or collapsed in time period 2. Our results showed that

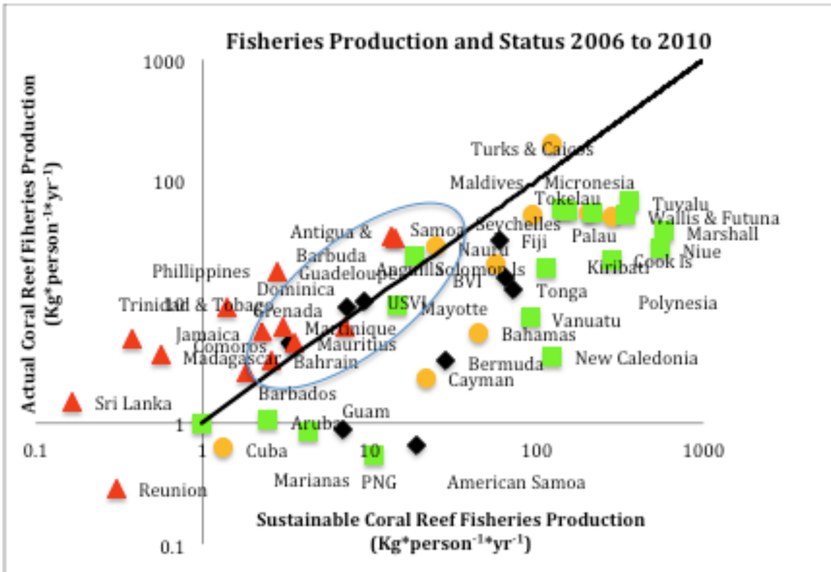

Fig.I. 5. Fisheries production status based on data from 2006-2010 (time period 2). Black represents countries with collapsed fisheries, red represents countries with overexploited fisheries, yellow represents countries with fully exploited fisheries, and green represents countries with underexploited fisheries. The black bold line represents the sustainable coral reef fisheries production of 5 mt km^{-2} yr^{-1}. The blue circle indicates the countries whose fisheries production status has changed from 1997 to 2001 (for comparison, see Figure 2).

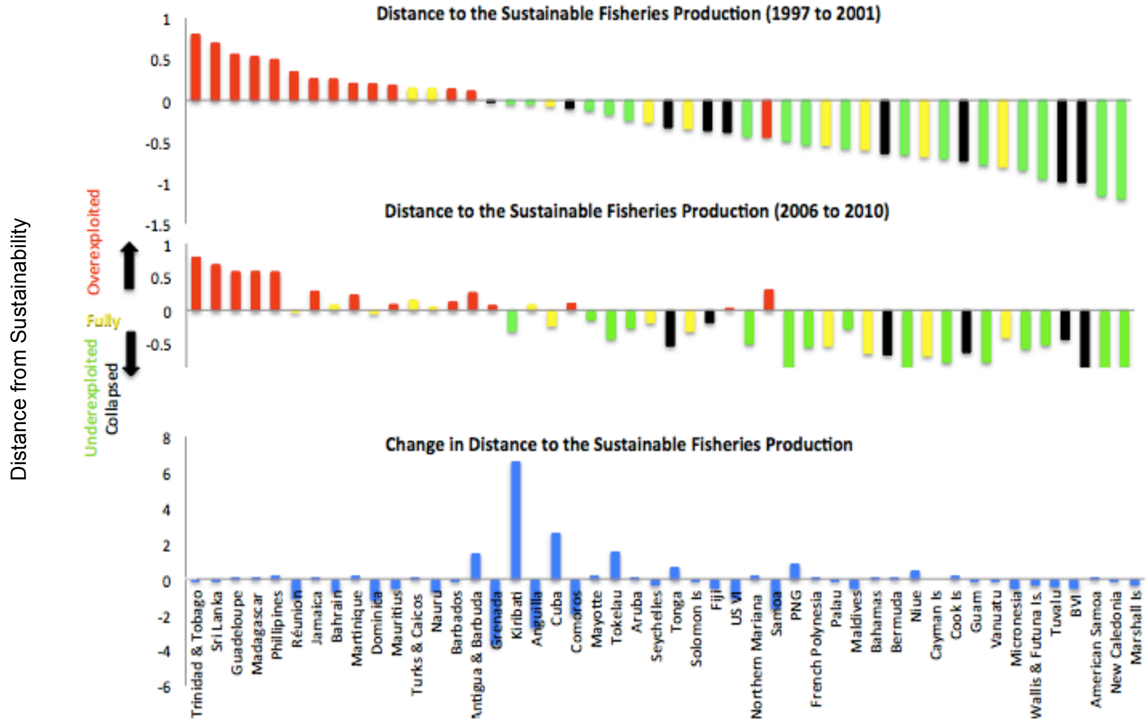

Fig.I. 6. The distance of actual fisheries production from the sustainable fisheries production. (a) Actual fisheries production from 1997 to 2001 (time period 1). (b) Actual fisheries production from 2006 to 2010 (time period 2). (c) The difference from both time series. Black represents countries with collapsed fisheries, red represents countries with overexploited fisheries, yellow represents countries with Fully exploited fisheries, and green represents countries with underexploited fisheries.

Table I.2: The statistical results for the change in actual fisheries production and socioeconomic factors.

Testes	R^2	F Ratio	P-Value
Change in Actual Fisheries Production vs in Change Population Growth	0.03	1.619	0.209
*Change in Actual Fisheries Production vs Change in Population Growth	<0.01	0.004	0.947
**Change in Actual Fisheries Production vs Change in Population Growth	<0.01	0.010	0.921
Change in actual fisheries production vs Gross Domestic Product (GDP)	<0.01	0.015	0.902
*Change in Actual Fisheries Production vs Gross Domestic Product (GDP)	<0.01	0.015	0.902
**Change in Actual Fisheries Production vs Gross Domestic Product (GDP)	0.10	1.622	0.223
Change in actual fisheries production vs Governance Indicator Index	<0.01	0.059	0.809
*Change in Actual Fisheries Production vs Governance Indicator Index	<0.01	0.059	0.809
**Change in Actual Fisheries Production vs Governance Indicator Index	0.03	0.322	0.581
Actual fisheries Status vs Governance Indicator Index	0.09	1.09	0.365
Governance Indicator Index vs Ocean Region	0.42	13.0	<0.001
Governance Indicator Index vs Gross Domestic Product	0.54	44.1	<0.001

* The 17 countries with the greater change in fisheries actual production

** The 17 countries with the greater change in distance from sustainable fisheries production

77.8% of fully exploited fisheries decreased in actual fisheries production. None of the countries had changed in their fisheries status between time periods 1 and 2. This result indicates that fisheries production in those countries hasn't increased as we hypothesized.

(1d) We expected that fisheries classified as underexploited in time period 1 would be underexploited, fully exploited, overexploited, or collapsed in time period 2. However, our results showed that actual fisheries production of underexploited fisheries increased only 37.5%, and only one country changed its fisheries status between time periods 1 and 2. Anguilla's fisheries shifted from underexploited to fully exploited, indicating that they are close to exceeding sustainable production (Fig.I.5 and I.6).

There was no correlation between ocean region and the change in actual fisheries production, indicating that the change in actual fisheries production is not a function of geographic location. Countries with the greater changes in both distance from the sustainable production line and actual fisheries production were not significantly related to ocean region and fisheries production status (Table.I.2).

I.4.2 Socioeconomic factors influencing island coral reef fisheries

(2a) Population Growth as a Cause of Change in Actual Fisheries Production

We expected that human population growth would be positively related to actual fisheries production over time. However, the results of the linear regression showed no significant relationship between the change in actual fisheries production and human population growth. The same result was obtained when we examined the change in actual fisheries production versus human population growth for the 17 countries with the greatest change between time periods 1 and 2 (Table I.2). These results indicate that population growth may not be a good predictor of change in actual fisheries production.

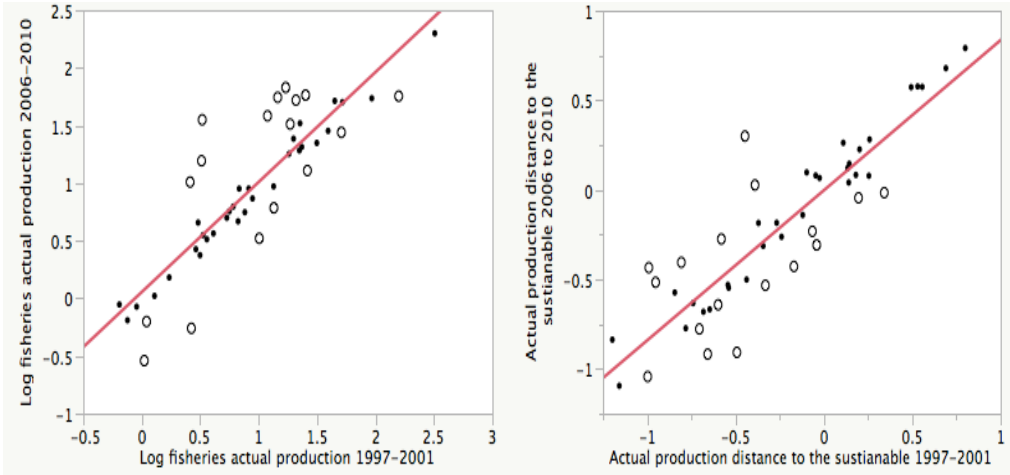

Fig. I. 7. (a) Countries with the greatest change in actual fisheries production between time periods 1 and 2. (b) Countries with the greatest change in distance to the sustainable production line between time periods 1 and 2. The black circles are represented by the countries with the greatest changes and the dots are the countries with minor changes from time period 1 to time period 2.

Table I.3:. Countries with the greatest change in actual fisheries production between time periods 1 and 2. .

Islands	Status	Ocean Region	Change in Actual Production
Bahrain	Overexploited	Other	-0.67
BVI	Collapsed	Caribbean	3.80
Cuba	Fully exploited	Caribbean	-0.43
Dominica	Overexploited	Caribbean	-0.55
Fiji	Collapsed	Pacific	0.74
Kiribati	Underexploited	Pacific	-0.64
Maldives	Underexploited	Other	1.30
Marshall Islands	Underexploited	Pacific	2.21
Micronesia	Fully exploited	Pacific	2.80
Niue	Underexploited	Pacific	-0.46
PNG	Underexploited	Pacific	-0.79
Réunion	Overexploited	Other	-0.73
Samoa	Overexploited	Pacific	9.75
Tonga	Collapsed	Pacific	-0.51
Tuvalu	Underexploited	Pacific	2.95
USVI	Collapsed	Caribbean	2.93
Wallis & Futuna	Underexploited	Pacific	1.51

Table I.4: Countries with greatest change in distance from the sustainable fisheries production line between time periods 1 and 2.

Islands	Status	Ocean Region	Change in Distance from sustainable production line
American Samoa	Collapsed	Pacific	0.05
Bahamas	Fully exploited	Caribbean	0.07
BVI	Collapsed	Caribbean	-0.56
Cook Islands	Underexploited	Pacific	0.10
Cuba	Fully exploited	Caribbean	2.56
Dominica	Overexploited	Caribbean	-1.23
Kiribati	Underexploited	Pacific	6.57
Maldives	Underexploited	Other	-0.53
Micronesia	Fully exploited	Pacific	-0.50
Niue	Underexploited	Pacific	0.40
PNG	Underexploited	Pacific	0.85
Réunion	Overexploited	Other	-1.05
Samoa	Overexploited	Pacific	-1.67
Tokelau	Underexploited	Pacific	1.53
Tonga	Collapsed	Pacific	0.61
Tuvalu	Underexploited	Pacific	-0.46
USVI	Collapsed	Caribbean	-1.07

For instance, Mayotte, a country with the third-highest population growth, shared the same underexploited fisheries status with Tokelau, which had negative population growth (decreasing population size) between time periods 1 and 2 (Table I.5).

(2b) Economic Growth as a Cause of Change in Actual Fisheries Production

We expected that economic development (as measured by GDP) would be negatively related to actual fisheries production over time, since wealthier countries can rely more on other means of income besides fishing. However, the results of the linear regression showed no significant relationship between economic growth (per capita GDP in USD) and change in actual fisheries production. The same results were obtained when we examined GDP versus the change in actual fisheries production of the 17 countries with the greatest changes in both distance to the sustainable line and actual production (Table I.2). These results indicate that economic growth may not be a good predictor of change in actual fisheries production. This is perhaps due to the lack of pattern in the economic growth among these countries. For example, Bermuda in the Caribbean, the wealthiest country in this study, shared the same collapsed fishery status as the Comoros in the Indian Ocean, one of the poorest countries in the world (Table I.5).

(2c) Governance Performance as a Cause of Change in Actual Fisheries Production

We expected that governance performance would be negatively related to actual fisheries production, such that countries with high governance indicators (good governance performance) will have more sustainable actual fisheries production. However, the results of the linear regression showed no significant relationship between mean governance performance index and change in actual fisheries production. The same results were obtained when we examined the 17 island countries with the greatest changes in both actual fisheries production and distance from the sustainable production line (Table I.2). Despite these results, countries with collapsed and

Table I.5: Human population growth, Gross Domestic Product (GDP) per capita, and governance index for the 48 island countries.

Islands	% Population Growth	GDP per Capita (USD)	Governance Index
American Samoa	0.78	8000	0.59
Anguilla	23.6	12200	1.41
Antigua &Barbuda	12.6	17800	0.86
Aruba	13.7	25300	1.29
Bahamas	18.4	31300	0.91
Bahrain	72.0	28700	0.49
Barbados	4.24	25000	1.09
Bermuda	3.36	86000	1.21
British VI	27.1	42300	NA
Cayman Islands	33.3	43800	1.09
Comoros	26.0	1300	-1.24
Cook Islands	11.5	9100	-0.84
Cuba	1.74	10200	-0.58
Dominica	1.21	14000	0.62
Fiji, Republic of	4.80	4700	-0.77
French Polynesia	13.0	22000	NA
Grenada	2.45	13500	0.26
Guadeloupe	7.64	7900	NA
Guam	3.24	28700	0.66
Jamaica	6.29	8900	-0.10
Kiribati	16.5	6200	-0.55
Madagascar	30.6	900	-0.68
Maldives	17.5	8900	-0.37
Marshall Islands	0.46	8600	-0.72
Martinique	4.78	14400	0.84
Mauritius	4.13	15400	0.82
Mayotte	33.9	4900	NA
Micronesia	-3.01	7100	-0.48
Nauru	0.12	5000	-0.29
New Caledonia	16.3	37700	NA
Niue	-20.5	5800	-0.78
N. Mariana .	-13.3	13600	NA
Palau	7.51	10500	-0.36
PNG	24.9	2700	-0.84
Philippines	18.9	4400	-0.40
Réunion	13.7	6200	0.97
Samoa	5.57	6200	0.11

Table I.5: *Continued*

Islands	% Population Growth	GDP per Capita (US$)	Governance Index
Seychelles	13.8	25000	-0.02
Solomon Islands	25.4	3300	-0.82
Sri Lanka	9.21	6000	-0.22
Tokelau	-26.3	1000	NA
Tonga	5.54	8000	-0.29
Trinidad &Tobago	3.99	19800	0.05
Turks and Caicos	62.3	29100	NA
Tuvalu	4.31	3400	-0.21
US Virgin Islands	-1.38	14500	0.91
Vanuatu	24.0	4800	-0.12
Wallis & Futuna	-4.08	3800	NA

* Population Growth was calculated as the percent difference from mean population of 1997-2001 and mean population 2006-2010.

Table I.6: The exploitation status of island coral reef fisheries in 1997-2001 (time period 1, n = 49) and 2006-2010 (time period 2, n = 48). The P values are from the student's t-test run to compare the mean changes in actual fisheries production between the two time points.

Island	Change in Actual Fisheries Production	P Value	Status 1997-2001	Status 2006-2010	Summary of Literature Research	References
American Samoa	No significant change	0.29	Collapsed	Overexploited	In 1996, 73% of the sites surveyed had low fish biomass; however, in 2002 only 32% had low biomass, with most sites showing moderate biomass. However, during an extensive coral reef survey in February 2004, NOAA divers noted an unusually low abundance of large fishes and sharks around the main islands, concluding that the abundance of target taxa such as groupers, snappers, giant clam, and parrotfish had declined.	[28, 42, 43]
Anguilla	Increased	0.02	Underexploited	Underexploited	Studies found no evidence of overfishing in the region, either in the mean size of parrotfish or in the range of sizes of groupers and snappers. Many sites showed very little change in fishing strategy. Also, Anguilla's reefs are structurally complex and may support greater fish productivity than less complex reefs.	[44, 45]
Antigua & Barbuda	Increased	0.02	Overexploited	Overexploited	An earlier study showed declines in average fish size and catch, in addition to algal overgrowth on some reefs, suggesting that the shallow reef fishery is overexploited around Antigua. Barbuda, on the other hand, has a smaller human population, which demands less finfish harvesting.	[38, 45]
Aruba	**No significant change**	**0.06**	**Underexploited**	**Collapsed**	Several causes of low fisheries performance include "overexploited coastal stocks, inadequate fishing equipment, and strong competition from Venezuelan fishing boats."	[46]
Bahamas	**Decreased**	**0.01**	**Fully exploited**	**Collapsed**	Earlier investigations indicated that target finfish species such as the Nassau grouper had harvest rates that were approaching the maximum sustainable yield levels. Overfishing, particularly in spawning aggregations, continues to be a problem throughout the Bahamas. Groupers and snappers were rare in many sites, and wrasses and surgeonfish dominated.	[47, 48]
Bahrain	Decreased	<0.01	Overexploited	Overexploited	Catches have declined due to the increase in fishing effort (both the number of boats and fishermen). Another factor is the use of destructive fishing techniques. Many target finfish target populations are declining or have almost collapsed. The combination of habitat destruction and overexploitation makes fishery recovery very challenging.	[49]
Barbados	No significant change	0.53	Overexploited	Overexploited	Investigations showed that some areas of reef are believed to be overfished, particularly on the south and west coasts, where fishers have reported reduced catch per unit effort and fish size.	[50]
Bermuda	No significant change	0.37	Collapsed	Collapsed	Study indicates that many coral reef species had been heavily harvested. Many species of top predators, in particular groupers, have not recovered from earlier overexploitation, which these species are rare in fish traps.	[48, 51]
British Virgin Islands	Increased	<0.01	Collapsed	Collapsed	Important top predators such as groupers appear to be in decline, as the size of the fish and change in catch composition show signs of overexploitation.	[45]
Cayman Islands	Decreased	<0.01	Fully exploited	Fully exploited	There was no significant difference in fish density between protected and non protected sites, a sign of high fish density in harvested areas. In February 2002, the Cayman Islands Government banned the fishing of Nassau grouper at spawning aggregation sites. Since then, no illegal poaching has been observed for this species. However, another study found that snappers showed signs of heavy exploitation.	[20, 33, 48, 52]
Comoros	Increased	0.04	Collapsed	Collapsed	Catches have declined in abundance, and mean fish size has declined. As much as 86% of the fishers saw declines in the species composition; many species are rare now. Another study confirmed that most of the fish appeared to be smaller than average, showing a clear sign of exploitation.	[53, 54]

Table I.6: *Continued*

Island	Change in Actual Fisheries Production	P Value	Status 1997-2001	Status 2006-2010	Summary of Literature Research	References
Cook Islands	Decreased	<0.01	Underexploited	Underexploited	Traditional protected areas are increasingly used as fisheries management tools. Although there is no clear sign of unsustainable fisheries, there are some species that need to be managed to prevent population declines.	[38, 55]
Cuba	Decreased	<0.01	Fully exploited	Fully exploited	At many sites, predators, herbivorous fishes, and invertebrates such as lobster, conch, and octopus all show declines due to harvesting. Large fish are rare. With large species in decline, fishers are harvesting other less valuable species such as rays, gray snappers, jacks, and grunts. Regardless, so far Cuba has healthier coral reef fish populations than other Caribbean islands such as Martinique, Guadeloupe, and Jamaica.	[48, 50, 56]
Dominica	Decreased	<0.01	Overexploited	Collapsed	Reef fish are threatened due to not only poor fishing practices but also habitat destruction and poor water quality, at least on the west coast. One of the most important reasons for fish decline is that Dominica has a narrow continental shelf, making fish more vulnerable to harvesting.	[57, 58]
Fiji, Republic of	Increased	<0.01	Collapsed	Collapsed	Recent reports suggested that certain target species had been overexploited. One possible cause in the declining of finfish is that management response to Fiji's dynamic reef fisheries is slow, and misdirected at increasing production rather than resource conservation and protection.	[38, 59, 60]
French Polynesia	Decreased	<0.01	Underexploited	Underexploited	On Fakarava atoll, finfish and invertebrate biomass are in good condition compared to Maatea, which is slightly lower than average, as the finfish have higher fishing pressure in that region. Finfish in Raivavae are better than the average across the island groups of French Polynesia. Overall, these islands don't show signs of heavy exploitation.	[61, 62]
Grenada	No significant change	0.09	Collapsed	Collapsed	Top predators are rare, and food fish showed clear signs of being heavily harvested.	[63-65]
Guadeloupe	No significant change	0.60	Overexploited	Overexploited	Total fish biomass has declined since 1980, and the island shows clear signs of finfish overexploitation.	[66, 67]
Guam	No significant change	0.35	Collapsed	Collapsed	Visual surveys have indicated the lack of large reef fish from many parts of the island. Medium-sized fish were common only in the north part of the island. No sharks were observed.	[43]
Jamaica	No significant change	0.96	Overexploited	Overexploited	Many studies have shown that fishermen often use illegal net sizes and fishing gear, leading to finfish overexploitation. Also, surveys indicate low fish population densities, and very few target taxa are present in the reef. For instance, only three of 16 finfish families could still be considered abundant.	[48, 68]
Kiribati	Decreased	0.01	Underexploited	Underexploited	In Abaiang, Abemama, Kuria, and Kiritimati, finfish biomass, size, and biodiversity suggests low levels of exploitation. Fish biomass is dominated by carnivores and top predators, a clear sign of a healthy fish community.	[38, 69]
Madagascar	No significant change	0.09	Overexploited	Overexploited	Apex predator and large fish that were once commonly caught along mangrove habitat are now extremely rare, which shows that finfish has been heavily exploited. Another study suggests that invertebrates are heavily harvested at an unsustainable level.	[31, 54, 70]
Maldives	Increased	<0.01	Underexploited	Underexploited	Maldives coral reef fishes are relatively undisturbed by fishing. Even though some of the largest fish were rare, parrotfishes and surgeonfish were abundant and unaffected by the presence of divers, which is typical behavior in an area where spearfishing and net fishing do not occur. Although groupers show signs of overexploitation, other species do not. Traditionally, tuna species have been harvested for subsistence, rather than coral reef fishes.	[29, 71]

Table I.6: *Continued*

Island	Change in Actual Fisheries Production	P Value	Status 1997-2001	Status 2006-2010	Summary of Literature Research	References
Marshall Islands	Increased	<0.01	Underexploited	Underexploited	A recent visual survey found large numbers of fishes, with no signs of overexploitation. However, sites such as, Likiep, Ailuk, Arno, and Laura showed some signs of decline in carnivores species.	[43, 72]
Martinique	No significant change	0.94	Overexploited	Overexploited	Finfish are overexploited in many sites. Fish abundance is higher inside marine protected areas, especially for the target species. Common invertebrate fishery targets such as spiny lobster have declined considerably.	[73, 74]
Mauritius	Decreased	<0.01	Overexploited	Overexploited	While no fish species is known to be threatened, illegal fishing is very common; consequently, fishing pressure is high. Finfish populations in lagoons appear to be overexploited.	[70, 75, 76]
Mayotte	Decreased	0.03	Underexploited	Underexploited	"Richness of fish species appears relatively homogeneous between sites when expressed as relative percentage per trophic category." Large fishes are dominant in the region, a good sign that target finfish have not been depleted.	[77]
Micronesia, Federated States	Increased	<0.01	Fully exploited	Fully exploited	As some regions of Yyi are not dependent on fish for income, even with a high fish consumption in the community, the density, size, biomass, and diversity of fish suggest that this environment is only lightly exploited. However, the status of finfish in some parts of Chuuk is poor, as the density, biomass, and biodiversity of the finfish were lower compared to Yyi.	[78, 79]
Nauru	Decreased	<0.01	Fully exploited	Fully exploited	Target fish species have declined due to intense fishing pressure on coral reefs.	[80-82]
New Caledonia	No significant change	0.71	Underexploited	Underexploited	In areas such as Ouasse, Thio, and Luengoni, finfish biomass is good in average, but biomass is lower than average in target species such as groupers and snappers. In Oundjo and Moindou, however, finfish are in poor condition, with signs of unsustainable exploitation.	[80, 83]
Niue	No significant change	0.10	Underexploited	Underexploited	Finfish stocks are in quite poor condition, but this may be due to environmental causes (lack of lagoon, remoteness, cyclone frequency) rather than fishing pressure.	[84]
Northern Mariana Is.	No significant change	0.71	Underexploited	Underexploited	Target taxa are abundant, but there is low fish biodiversity compared to the southern islands.	[43]
Palau	No significant change	0.57	Fully exploited	Fully exploited	Earlier fish surveys and fishers observations suggested a decline in fish populations. However, a recent study indicates that overall, finfish have good to average density and size in all four sites studied with the exception of Airai, which showed lower than average fish biomass and size.	[43, 85]
Papua New Guinea	Decreased	0.04	Underexploited	Underexploited	In Andra, Tsoilaunung, and Sideia, finfish are slightly to moderately impacted by fishing, with biodiversity, and biomass, and density good overall. Also, carnivores and top predators, such as sharks, were common.	[23, 86]
Philippines	Increased	0.01	Overexploited	Overexploited	In all 8 sites surveyed, finfish have been declining over time, and their populations are generally depleted.	[87, 88]
Réunion	Decreased	0.03	Overexploited	Overexploited	Top predator density is low, a clear sign of overharvesting. Subsistence fishing has increased proportionately with increasing unemployment rates, and the target finfish are reef fishes.	[76]
Samoa	Increased	<0.01	Overexploited	Overexploited	Finfish in sites such as Manono-uta and Vailoa appeared to be in good condition, with high biomass, density, and size compared to other sites such as Salelavalu. However, giant clams seemed to be overexploited at all sites.	[89]

Table I.6: *Continued*

Island	Change in Actual Fisheries Production	P Value	Status 1997-2001	Status 2006-2010	Summary of Literature Research	References
Seychelles	No significant change	0.14	Fully exploited	Fully exploited	Study indicates overfishing of the most target finfish, such as red snapper. Sea cucumber and lobster are indicated of being overexploited.	[54]
Solomon Islands	No significant change	0.45	Fully exploited	Fully exploited	Low abundance of clams and scarcity of large fish suggest that overfishing has happened in some islands of the group. Additionally, finfish biomass was high at some islands, whereas in other regions density and biomass were lower than average; this seems to be in the margin between a fully exploited and overexploited system.	[12, 80, 81]
Sri Lanka	No significant change	0.41	Overexploited	Overexploited	Destructive fishing practices have lead to a decline in coral reef finfish.	[90]
Tokelau	Decreased	<0.01	Underexploited	Underexploited	There has been little finfish decline and little threat of overfishing.	[91]
Tonga	Decreased	<0.01	Collapsed	Collapsed	In Ha'atafu and Koulo, finfish were lower than average, with the mean sizes of several fish families below 50% of the maximum values. In Manuka, finfish had low biomass and size. Previously abundant giant clams are now rare according to fishers' observations.	[2, 92-94]
Trinidad & Tobago	No significant change	0.64	Overexploited	Overexploited	The artisanal groundfish fishery showed a major decline in yield and biomass. The majority of the coral reef fisheries are either fully exploited or overexploited.	[95]
Turks & Caicos Is.	Decreased	<0.01	Fully exploited	Fully exploited	Fishing pressure is relatively low, and the fish community is mostly in good condition on both islands. Fishermen reported that fish density has not changed since 2004.	[48]
Tuvalu	Increased	<0.01	Underexploited	Underexploited	Even though surveys at Funafuti and Vaitupu showed early signs of finfish decline, in Nukufetau and Niutao finfish were found to be in good condition.	[80, 96]
US Virgin Islands	Increased	<0.01	Collapsed	Collapsed	Populations of targeted taxa such as groupers and snappers have not recovered. In addition, only 2% of the targeted species were greater than 35 cm in length. Spiny lobster and conch have decreased in size.	[43]
Vanuatu	Decreased	0.07	Underexploited	Underexploited	There is no sign of heavy exploitation, as there is large size and biomass of carnivores and herbivores in the 5 sites surveyed: Paunangisu Village, Moso Island, Uri Island, Uripiv Island and Maskelyne Archipelago.	[81, 97]
Wallis & Futuna Is.	Increased	<0.01	Underexploited	Underexploited	In Wallis, finfish appeared to be in relatively good condition. In Futuna, however, finfish have shown signs of decline due to the poor availability of reef habitats.	[98]

overexploited fisheries had the highest mean governance performance indexes, and most of the countries with underexploited and fully exploited fisheries had the lowest governance performance indexes (Table I.5).

I.5 Discussion

I.5.1 Change in actual fisheries production between 1997-2001 and 2006-2010

In this study, we compared the actual fisheries production over a 10-year period for 48 islands across the tropics. Our first goal was to determine the change (if any) in actual fisheries production based on the sustainable production. Of the 48 countries studied here, fisheries in Bahrain, Dominica, and Réunion went from overexploited to fully exploited, fisheries in Grenada, Comoros, and the US Virgin Islands went from collapsed to overexploited, and fisheries in Anguilla went from underexploited to fully exploited.

There are several possible explanations of how a collapsed fishery can recover in only 10 years, as suggested by the results from the countries Comoros, Grenada, and the US Virgin Islands. Perhaps management was especially effective, allowing fish populations to recover. Maybe, effort has been shifted away from collapsed species and onto less exploited species.

When there are so many factors to consider in determining fisheries overexploitation, defining sustainability becomes a challenge. Overfishing can be categorized in a variety of ways: economic overfishing, growth overfishing, recruitment overfishing, ecological overfishing, and Malthusian overfishing [99, 100]. Economic overfishing occurs when fishing effort surpasses the requirement to achieve the maximum economic yield. Growth overfishing occurs when there are no large individuals in the population, and the remaining individuals are heavily fished before reaching a optimum size. Recruitment overfishing occurs when individuals are so heavily fished before they reach their reproductive age and size that production of larvae and recruitment are compromised [101]. Ecological overfishing occurs when fish have been so heavily exploited (affecting both relative abundance of a species and species composition) that fishers must instead target less valuable and nutritional species [99]. Malthusian overfishing occurs when fisheries harvest is too intense to be sustainable, and fishers use destructive methods in an attempt to increase catch [100].

For simplification, our literature review considered overfishing to occur when the quantity of fisheries harvest passed the biological limits of a certain resource. In other words, this occurs when fish catch surpasses the maximum sustainable yield (MSY) and starts to drop for all fishers, and "the number of fish drops to a level lower than required for maintaining a viable and productive fish population" [87].

Newton et al. (2007) classified fisheries as overexploited when fisheries production were above the sustainable production line, according to the mean landings per capita (actual production) as a function of coral reef area and the MSY of 5 mt km^{-2} yr^{-1} (sustainable production). Note that the variables used here to define actual fisheries production and fisheries sustainable production have many limitations, from the FAO data and collection of the fisheries landings to the fixed number used for determinations of MSY used.

Maximum Sustainable Yield from Coral Reef Fisheries

Dalzell (1996) defined yield as "primarily a function of fishing effort, and this varies greatly among reefs of the world" [18, 102, 103]. The effort at one location can be dramatically different compared to another [13, 18]. To this day, there is great confusion surrounding the calculation of coral reef fisheries yield; for example, shellfish is harvested at low tide, so the effort is different from the effort of harvesting finfish from the reef slope. Another cause of variability in coral reef fisheries yield is that some people include yields from lagoons, mangroves, sand beds, and sea grass beds [102].

To make these calculations more standardized, it was suggested that 40 m depth should be the depth limit, as this is the limit of coral growth and coincides with the depth range most small-scale fishing techniques [18, 101]. More recent studies applying these standardized calculations have reported coral reef fisheries yields from 0.2 mt km^{-2} yr^{-1} in Papua New Guinea to 40.0 mt km^{-2} yr^{-1} in American Samoa. Eight of these 10 studies have reported that sustainable coral reef fisheries yields are between 5 and 10 mt km^{-2} yr^{-1} [13, 101, 102].

In this study, we followed Newton et al. (2007) by using 5 mt km^{-2} yr^{-1} as a sustainable coral reef fisheries yield for all 48 countries. This agrees with Dalzell (1996), who states that yields of 5 mt km^{-2} yr^{-1} are “probably” sustainable in the long term. However, because fisheries yield is a function of fishing effort (and is also affected by human population density), it can vary even within the same location (e.g. 2.9–3. 7 mt km^{-2} yr^{-1} for Fiji). The degree of harvesting is different from one island to another, making the value of 5 mt km^{-2} yr^{-1} unsustainable or an indication of overfishing in some locations [104]. Even though, in many cases, a generalized sustainable yield value can therefore produce inaccurate fisheries status, this fixed number reflects the need of a generalized MSY.

Limitations of Small-Scale Fisheries Data

Typically, it is extremely challenging to quantify fish catch, particularly for small-scale fisheries. SSF data therefore have several limitations, including: (1) many coral reef SSF show no clear seasonality; and fishers harvest through the year as needed, using many types of gear [13, 18]; (2) SSF are usually multispecies fisheries with multiple landing sites [18, 28, 101]; (3) the term “small-scale fisheries” has many interpretations in different locations: What might be considered artisanal in one country could be seen as commercial in another, and this impacts the submission of fishery statistics [105]; (4) fishers might feel pressured and misreport the catch length and with that produce bias so, underreported fisheries are almost unknown and consequently not estimated [41]; (5) because SSF are multispecies fisheries, sometimes the catch might have as much as 100 species of fish; due to different common names among locations, one species of fish might have many names, leading to grouping species within categories and preventing assessments of individual species [13, 18, 19, 105]. As a result, many countries with SSF landings reported to the FAO include data categorized as marine fisheries not elsewhere included (nei), as described below [28].

FAO Marine Fisheries Not Elsewhere Included (nei)

FAO landings reports include a category called marine fisheries not elsewhere included (nei). These are the fish that could not be separated by taxa. Most of the island nations investigated in this study are heavily dependent on pelagic tuna for exportation and on coral reef fisheries for local consumption [41]. Because of their high profits, tuna fisheries receive far more attention and are thus generally better reported at the national level. The practice of reporting landings in artisanal and subsistence fisheries is often absent in developing countries because it was only recently that small-scale fisheries have become the subject of scientific interest; thus the need to gather data is comparably new in relation to industrial fisheries.

For all these reasons, SSF data are generally underestimated in official statistics [106]. Therefore, the results of this study should be interpreted conservatively. Countries with underexploited fisheries might actually be overexploited due to additional, unreported fisheries landings. In the same way, countries with collapsed fisheries in

1997-2001 that showed increased fisheries production between then and 2006-2010 might have shifted in target species.

I.5.2 Socioeconomic factors influencing island coral reef fisheries

Our second goal was to investigate socioeconomic factors such as population growth, economic growth, and governance performance to understand the change in actual fisheries production over a 10-year time period.

(2a) Population growth and fisheries production

It is clear that the increase of fishing could lead to resource depletion [13, 18, 19, 26, 107]. Many of the countries with high population growth have overexploited fisheries due to the ever-increasing “demand for food fish, low operating cost and lack of alternative employment” [99], especially in island countries [26]. Increasing population leads to increasing demand, which leads to overharvesting. While this is true in many site-specific case studies, our results demonstrate that this pattern does not necessarily hold across many countries at a global scale.

Indeed, while population growth could be an important element to define fisheries status in some locations, it likely cannot be generalized across the tropics because so many other factors can strongly influence fisheries production. In heavily populated Papua New Guinea, for instance, SSF are mostly for subsistence, and “catches are made to satisfy only immediate food requirements” [18]; Newton et al., (2007) states that PNG fisheries are thus underexploited. In contrast, the British Virgin Islands has a smaller population but most of the fish is heavily harvested to be sold in markets as BVI is determined in this study collapsed. Coral reef SSF are a multifaceted systems, and the connection between human population and harvesting can be influenced not only by population growth but also by other factors in the socioeconomic spectrum [13] Are economic development and governance performance better indicators, then, of coral reef fisheries status of tropical island countries?

(2b) Economic growth and fisheries production

The economic growth of a country can significantly affect the status of many fisheries [16, 18]. There are both positive and negative effects that must be considered.

Positively, greater economic development can facilitate more sustainable fisheries because it provides more opportunities for different incomes. For example, despite its small size, Nauru is a prosperous country due to phosphate mining [18]; thus, there is no pressure to generate income from fishing. Most Nauru's fisheries are recreational. Based on our study, Nauru has a fully exploited coral reef fishery, which is considered sustainable overall. In contrast, many countries with low gross domestic product (GDP) have fewer economic opportunities; consequently, more people harvest fish in a unsustainable way (Malthusian overfishing [100]), and there is greater pressure on the fishery resources [18].

However, economic growth can also introduce a more Westernized way of living [16], change the property regime of an area from traditional to open access (based on the "tragedy of commons" concept [108]), and introduce modern harvesting gear and cash exchange for fish, all of which can lead to overexploitation and eventual collapse of recourses [19]. For instance, fishing grounds under traditional customary marine tenure (CMT) had higher density and reef fish biomass compared to ones with more urbanized areas and more modern management practices [26].

Even though site-specific studies have shown that economic growth strongly affects fisheries, in this study, economic growth (approximated by GDP) had no significant relationship to the change in actual fisheries production for the 48 island countries studied. For same areas economic growth might be positive, reducing fishing pressure, and while economic growth may have declined in other areas, increasing the likelihood of fisheries overexploitation.

(2c) Governance performance and fisheries production

Socioeconomic factors such as lack of opportunities, hunger, and poverty are strong drivers of illegal fishing and mostly occur in situations of poor fisheries management and control. In the absence of effective governance, natural resources are in danger, especially from increasing human population [101] and the use of advanced technologies for resource extraction, both of which lead to a collapsed system [107]. We therefore assumed that fisheries status would be related to governance indicators, which measure the effectiveness or performance of a government and are important in better understanding the role of accountability in governments [109].

We assumed that countries with collapsed and overexploited fisheries would also have the lowest governance performance scores, but our results showed no significant relationship between these variables. We did find a significant relationship between ocean region and the governance performance index (Table I.2); the Caribbean appeared to have the highest governance performance, while the Pacific appeared to have the lowest governance performance. Interestingly, Pacific countries have more sustainable or underexploited fisheries, while Caribbean countries have more overexploited fisheries (Table I.1). A possible reason for this discrepancy is that most countries in the Pacific are structured differently from the other regions, in that there are many little isolated islands, each with its own small local government [26, 27, 59]. Also, countries with a more westernized system might need to have higher governance performance, as the need of resource protection increase with open access and cash economies. This is supported by the significant linear relationship between gross domestic product (GDP per capita) and governance performance index (Table I. 2 and

I.5).

We were not able to compare these results to any other published studies, as in our literature review we did not find any study comparing the relationship between governance indicators and small-scale fisheries; the studies available were related to illegal, unreported, and unregulated fisheries (IUU) on the high seas or offshore EEZ zones. Nonetheless, based on our results governance indicators may not be good predictors of coral reef fisheries production at a global scale due to among-country differences in public perception of government performance.

I.6 Conclusions

While many studies of SSF have shown that their production is related to socioeconomic factors, most such studies are regional only. Broad global overview studies like Newton et al. (2007) are important in focusing attention on the importance of SSF thus decrease their marginalization. This will improve data collection and reporting and open more opportunities for accurate research, perhaps ultimately supporting more effective management and conservation.

In this study, we analyzed whether the historical status of a fishery or associated socioeconomic factors could be used as generalized indicators of coral reef fisheries exploitation in countries across the tropics. In short, we found no strong predictive capability of any proposed metric. Our results help to highlight a general shortcoming of global comparative studies on this topic, which fail to consider factors that are unique to each location such as economic development, distance to markets, culture, dependence on fish resources, political issues, geography, religious views, and environmental factors. All of these factors make global comparisons challenging if not impossible, because among-country differences mean that fisheries status cannot be interpreted accurately without its local context.

The human and coral reef fisheries relationship, even with few similarities cannot be simplified as homogenous across the globe [99]. In short, fixed data cannot necessarily be used to generalize the complexity of the ever-changing dynamics between humans and small-scale fisheries, especially when it is in large scale.

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Chapter II

A rapid assessment of small-scale fisheries in the Kingdom of Tonga: a case study

Abstract

Among the 147 islands that constitute the Kingdom of Tonga, only 37 are inhabited. Tongatapu is the most developed of the three main islands, and Ha'apai is the least developed.

Finfish from small-scale fisheries provide for both islands the main source of protein with reef finfish comprising almost 70% of total landings. To assess how urbanization and westernization have affected Tongan fisheries, we used fully structured interviews in households at both islands to determine fishers' perception of change in coral reef fisheries. Our results suggest that on Tongatapu, the more developed island, fish size has decreased over time, but overall catch has increased, despite fishers spending a similar amount of time fishing. On Ha'apai, the less developed island, fishers also perceived a decrease in fish size, and in catch even though they are spending more time fishing. This case study reaffirms that, while large-scale studies such as discussed in Chapter I are often depended upon to highlight the unique issues associated with small-scale fisheries, localized case studies provide a better and more meaningful way of assessing the true condition of fisheries.

II.1 Introduction

Tonga, the only kingdom in the Pacific [110] (Figure 1), consists of 174 scattered islands and islets, of which only 37 are inhabited [2, 111, 112]. The population of approximately 104,000 people [39] are mostly small-scale fishers [2], subsistence farmers (sweet potato, yam, and manioc are the main crops) [92, 113] and hand crafters and weavers [114, 115]. Of these activities, small-scale fishing is the most important source of livelihood in the archipelago [115, 116] and mostly targets finfish and invertebrates associated with coral reefs. Finfish from coral reef fisheries provide Tongan's main source of protein [2, 113, 117], with shallow-water reef finfish comprising almost 70% of total landings [2].

There are three main islands in the archipelago: Tongatapu, Ha'apai, and Vava'u. Tongatapu is the more urbanized and populous (around 71,000 people) of the three islands [92, 112, 118, 119], and the location of Tonga's capital, Nuku'alofa. Ha'apai, with a population of 6,000, is the least developed of the three main islands [26, 113-115, 119]. Vava'u, with approximately 14,000 people, has an intermediate level of development and is the most visited by tourists [111].

Even though fisheries in the Kingdom of Tonga are considered traditional with a "non profit-seeking private enterprise" [92], in which most of the fishers have a subsistence lifestyle supported by the previous generation's knowledge systems [17], cash exchange for fish has increased, especially on Tongatapu [2] (Table I.1). Knowing that the increase of markets and open access in the more urbanized areas results in finfish decline [2, 111, 113, 115, 120], consistent with the "tragedy of commons" phenomenon [108], the goal of this study is to assess the small-scale fisheries at Tongatapu and Ha'apai in order to determine if the socioeconomic development of an area affects small-scale fisheries. We hypothesize that more urbanization and westernization (more development) leads to overexploitation of resources, in this case coral reef fisheries, as a response to the increase in cash-based exchange of resources as opposed to the traditional non-monetary resource sharing.

Table II.1: Subsistence and commercial fisheries: Annual mean production of subsistence and commercial from 1989 to 1992. This table was cited by [2], concluding that more fishers in Tongatapu are engaged in fishing for cash exchange than in Ha'apai.

	Commercial	Subsistence	Total
Nuku'alofa	1,000	375	1,375
Vava'u	250	280	530
Ha'apai	100	180	280
Other	79	98	177
TOTAL	1,429	933	2,362

FAO Digital Atlas, 1998

II.2 Methods

II.2.1 Investigation site

The two study sites (Fig.II.1) were chosen because they share a great dependency (direct or indirect) on small-scale fisheries but have different social and economic conditions, such as variation in degree of isolation, market influence, and dependence on other marine resources [23].

Tongatapu is urbanized, with relatively big shopping stores, a main fish market, public transportation, Internet cafes, and many international restaurants and hotels. Ha'apai is less developed, with few *fale koloa* (small corner shops supplying people with basic goods), one small market that is only open on Saturday mornings, and no fish market; fishers share and sell their catch anywhere in the village. This is due to Ha'apai's geographical isolation compared to Tongatapu [116]. While Tongatapu can be easily accessed by regular international flights, in Ha'apai the local airline company operates (very expensive) flights only once per week, and the ferry ride from the nearest island takes around 8 hours.

II.2.2 Household interviews

We interviewed fishers in Tongatapu and Ha'apai in 2012 in order to obtain information on fishing performance and perceptions of resource change. Our goal was to collect data on the major habitats targeted, fishing techniques (types of fishing gear and boat usage), frequency of the trips (hours per month), purpose of fishing (subsistence or profit-based), and the size and amount of fish caught currently compared to when fishers first started to fish.

Household interviews were conducted using a standard semi structured closed questionnaire survey in the major communities on both islands. We followed the Snapshot Assessment Protocol (SNAP) of the Small-Scale and Artisanal Fisheries Research Network (SAFRAN), based at Scripps Institution of Oceanography [121]. This assessment was part of a pilot field project in ten countries to test the viability of the SNAP, which was intended to collect small-scale fisheries data in order to enhance "communication and collaboration across disciplines, projects, and sectors; share research guidelines and methodologies; and connect research to meaningful management actions" [121] .

Because the majority of the population on both islands fishes, the interviewees were chosen randomly. The interviews lasted 30-45 minutes each and were conducted either in Tongan or in English, according to fishers' language preference. Numerous local trained assistants were hired as translators; we mostly chose people that had some relationship with fisheries or fishers. Knowing that small-scale coral reef fisheries are multi-species, and that different villages may have multiple different names for a single species, we used fish pictures and a list of fish species translated from Tongan to English in all interviews (Table II.5 and II.6).

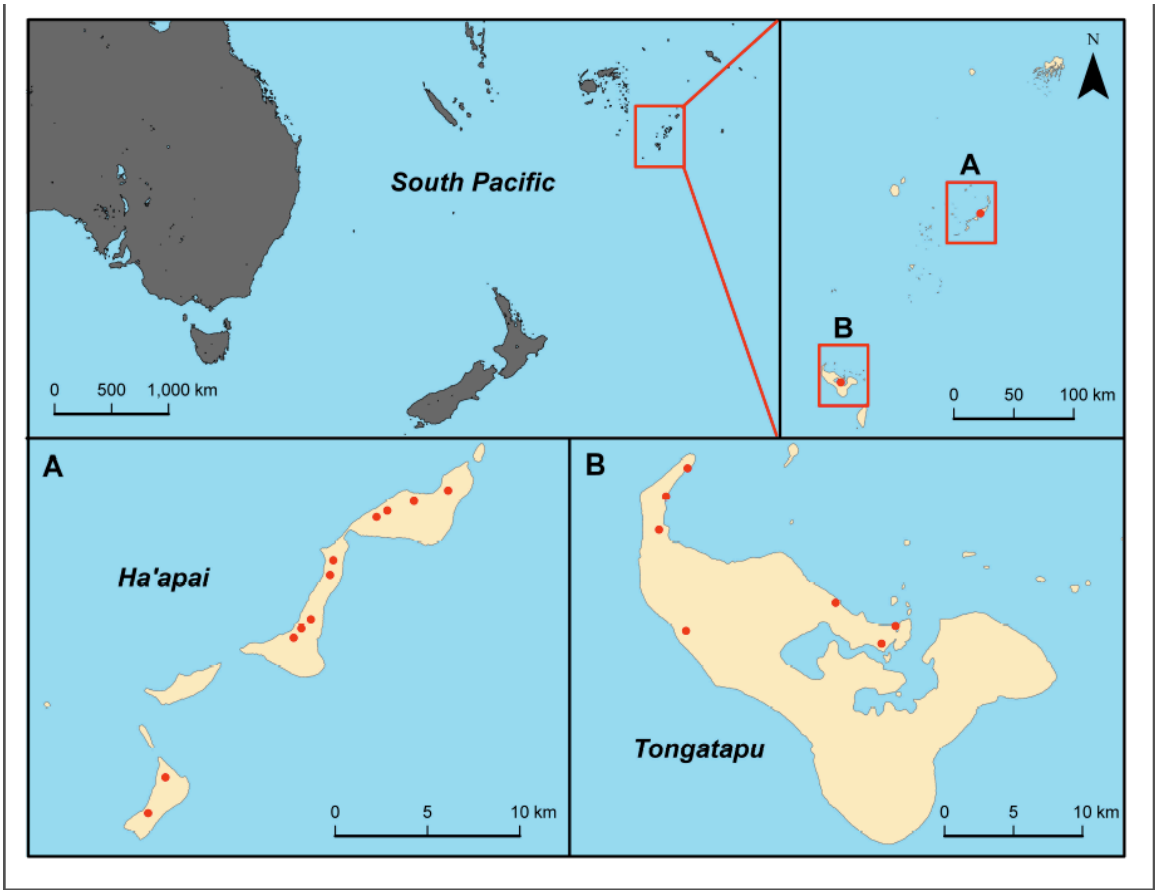

Fig. II.1. Map of the Kingdom of Tonga showing both study sites, Tongatapu and Ha'apai. The red dots indicate the locations of the villages in which surveys were conducted. *Map credit: Clinton Edwards.*

II.3 Results

We conducted a total of 107 in-person interviews, 52 in Tongatapu and 55 in Ha'apai. On Tongatapu, 88.5% of respondents said that selling finfish was very important, while only 63.6% of respondents in Ha'apai confirmed that the purpose of fishing was to sell their catch. Accordingly, results indicated that most fishers on Ha'apai (96.4%) bring their catch home or share it in their community (Table II.1). On both islands, around 70% of respondents had parents who were fishers, and more interviewees in Tongatapu expressed a wish to pass on their fishing knowledge to their children (Table II.2).

Table II.2. Demographic characteristics, the purpose of fishing, and tradition in the villages surveyed.

	Tongatapu	Ha'apai
Population	71,000	6000
Total number of interviews	52	55
Average age	45	48
Average years fishing	26	29
Fishing purpose:		
to eat	82.7%	96.4%
to sell	88.5%	63.6%
Tradition:		
parents fished	71.2%	72.7%
wishes to pass tradition to children	63.5%	51%

Table II.3. Fishing techniques, time spent fishing, and areas of coral reef habitat targeted for fishing (all shown as mean hours per month).

	Tongatapu	Ha'apai
Fishing techniques:		
speargun	10.25	8.37
handline	7.32	2.94
invertebrate harvest	4.95	1.55
throw net	3.94	1.66
gill net	2.46	1.94
rod and reel	0.69	1.26
Total mean hours per month	29.61	17.72
Boat usage (unit):	35	27
Boat owner	31%	16%
Area used to fish:		
lagoon	33	26
reef flat	19	25
reef slope	19	29
deep water	14	19

Both islands used the same fishing techniques, and most of the fishers preferred to use spearguns and handlines or a combination of two or more techniques. Handlining is an easier technique, as it requires less gear, but the catch is random. Spearfishing requires more labor and gear, because fishers must dive to catch the fish, but the catch is less arbitrary [94]. Most of the fishing grounds, especially the ones where fishers use spearguns, are reached by boat (Table II.3).

Fishers in Tongatapu preferred to fish in the lagoon area of the coral reef, and fishers in Ha’pai preferred the reef slope (Table II. 2). In Tongatapu, snappers (lutjanids) were the most targeted finfish and octopus were the most targeted invertebrates, whereas in Ha’apai unicornfish (acanthurids) were the most targeted finfish and lobster were the most targeted invertebrates (Table II.4).

Table II.4. Fish and invertebrate catch composition and percentage of respondents who mentioned each group as a fishing target.

Tongatapu		Ha'apai	
Finfish	**%**	**Finfish**	**%**
Snapper spp.	83	Unicornfish spp.	65
Grouper spp.	50	Grouper spp.	60
Emperor spp.	37	Emperor spp.	53
Unicorn spp.	31	Surgeonfish spp.	36
Mullet spp.	29	Moray eel spp.	33
Parrotfish spp.	27	Snapper spp.	29
Tuna spp.	25	Parrotfish spp.	25
Trevally spp.	19	Trevally spp.	20
Shark spp.	13	Lunar tail rockcod	20
Moray eel spp.	12	Rabbitfish spp.	18
Angelfish spp.	8	Rudderfish spp.	18
Barracuda spp.	6	Tuna spp.	15
Rabbitfish spp.	6	Grey reef shark	15
Milkfish spp.	6	Jobfish spp.	15
Triggerfish spp.	6	Coral trout	11
Silverbiddy spp.	6	Mullet spp.	11
Ray spp.	4	Angelfish spp.	9
Surgeonfish spp.	4	Covict tang	7
Squirrelfish spp.	4	Rainbow runner fish	7
Lunar tail rockcod	4	Bigeye scad	7
Ponyfish spp.	4	Goatfish spp.	5
Rudderfish spp.	2	Milkfish spp.	5
Goatfish spp.	2	Whitefish spp.	2
Porcupine spp.	2	Wrasse spp.	2
Jobfish spp.	2	Squirrelfish spp.	2
Scads spp.	2	Turtle spp.	2
Grunts spp.	2	Triggerfish spp.	2
Wasse spp.	2	Seabream spp.	2
Rainbow runner fish	2		
Invertebrates	**%**	**Invertebrates**	**%**
Octopus spp.	25	Lobster spp.	9
Shellfish spp.	15	Shellfish spp.	7
Lobster spp.	13	Sea cucumber spp.	7
Sea cucumber spp.	13	Spider conch spp.	4
Crab spp.	4	Octopus spp.	2
Sea urchin spp.	2		

Table II.5. Fish nomenclature in Tongatapu in English and in Tongan [1].

No.	English	Taxonomic	Tongan
1.	tiger shark	*Galeocerdo cuvieri*	*'anga takaneva*
2.	grey reef shark	*Carcharhinus amblyrhynchos*	*'anga*
3.	hammerhead shark	*Sphyrna lewini*	*mātai*
4.	eagle ray	*Aetobatus narinari*	*fai sikotā*
5.	manta ray	*Manta birostris*	*fai manu*
6.	moray eel	*Gymnothorax* sp.	*toke*
7.	emperor	*Lethrinus olivaceous*	*ngutukao*
8.	emperor	*Lethrinus erythracanthus*	*koputu*
9.	surgeonfish	*Ctenochaetus striatus*	*pono*
10.	striped surgeonfish	*Acanthurus lineatus*	*tuhi*
11.	unicornfish	*Naso unicornis*	*'ume*
12.	rabbitfish	*Siganus argenteus*	*ōō*
13.	rudderfish	*Kyphosus cinerascens*	*nue*
14.	angelfish	*Pygoplites diacanthus*	*sifisifi*
15.	squirrelfish	*Sargocentron* sp.	*telekihi*
16.	batfish	*Platax teira*	*sifisifi naivatu*
17.	lunar tail cod	*Variola louti*	*ngatala kula*
18.	blue spotted grouper	*Cephalopholis argus*	*ngatala 'uli*
19.	coral trout	*Cephalopholis miniatus*	*ngatala pulepule*
20.	giant grouper	*Epinephelus lanceolatus*	*popo*
21.	spotted grouper	*Epinephelus tauvina*	*tonu*
22.	snapper	*Lutjanus* sp.	*palu*
23.	red snapper	*Lutjanus* sp.	*fangamea*
24.	oilfish	*Ruvettus pretiosus*	*mōmoto*
25.	jobfish	*Aprion virescens*	*tokoni fusi*
26.	rainbow runner	*Elagatis bipinnulata*	*'utu mea*
27.	dolphinfish	*Coryphaena hippurus*	*mahimahi*
28.	great barracuda	*Sphyraena barracuda*	*hapatū*
29.	striped marlin	*Tetrapturus audax*	*neiufi*
30.	sailfish	*Istiophorus platypterus*	*hakulā*
31.	bluefin trevally	*Caranx melampygus*	*lupo*
32.	trevally	*Caranx sexfasciatus*	*lupolupo*
33.	silver scad	*Selar crumenophthalmus*	*mataheheva*
34.	skipjack tuna	*Katsuwonus pelamis*	*'atu*
35.	yellow-fin tuna	*Thunnus albacares*	*kahikahi*
36.	flying fish	*Cypselurus naresii*	*sikotā tahi*
37.	needlefish	*Strongylura leiura*	*haku*
38.	porcupine fish	*Diodon hystrix*	*sokisoki*
39.	pufferfish	*Arothron hispidus*	*te'e te'e*
40.	goatfish	*Parupeneus* sp.	*tukuleia*
41.	milkfish	*Chanos chanos*	*te'efō*
42.	grey mullet	*Mugil cephalus*	*kanahe*
43.	maori wrasse	*Cheilinus undulatus*	*tangafa*
44.	filefish	*Aluterus scriptus*	*papae*
45.	triggerfish	*Balistoides viridescens*	*hūmu*
46.	parrotfish	*Scarus rubroviolaceus*	*holoveka*
47.	parrotfish	*Chlorurus* sp.	*menenga*
48.	parrotfish	*Chlorurus microrhinos*	*sika toki*
49.	anenomefish	*Amphiprion chrysopterus*	*?*
50.	remora	*Remora remora*	*tellteli'uli*

Source: RCM. Vava'u, Tonga Field Records, 1982; Taveuni, Fiji Field Records, 1996.

Table II.6. Fish nomenclature in Ha'apai in English and Tongan [115].

ENGLISH NAME	TONGAN NAME	SCIENTIFIC NAME
Barred garfish	*Hu'ila*	*Hemirhamphus far*
Bicolor parrotfish	*Hohomo*	*Cetoscarus bicolor*
Convict surgeonfish	*Manini*	*Acanthurus triostegus*
Darkfinned Barracuda	*Momotu*	*Sphyraena qenie*
Dogtooth tuna	*Valu*	*Gymnosarda unicolor*
Emperor fish	*Fangamea*	*Lethrinus* sp.
Goatfish	*Vete*	*Mulloidichthys vanicolensis*
Grouper	*Ngatala*	*Epinephelus* sp.
Horse mackerel	*'Otule*	*Selar* sp.
Long tom	*Haku*	*Tylosurus crocodilus*
Mullet	*'Unomoa*	*Liza macrolepis*
Parrotfish	*'Ufu*	*Leptoscarus vaigiensis*
Parrotfish	*Pose*	*Scarus* sp.
Pufferfish	*Te'ete'e*	*Arothron manilensis*
Pufferfish	*Pe'e*	*Lagocephalus* sp.
Rabbit fish	*Ma'ava*	*Siganus argenteus*
Spinefoot rabbitfish	*O*	*Siganus spinus*
Snapper	*Palu*	*Etelis coruscans*
Surgeonfish	*Pone*	*Acanthurus* sp.
Sardine	*'Ulukau*	*Sardinella* sp.
Stonefish	*Nofu*	*Synanceia verrucosus*

Our interviews showed that 50% of respondents in Tongatapu perceived that they are catching more fish now compared to when they started to fish, while in Ha'apai 43.6% of respondents perceived that they are catching less fish now compared to when they started to fish. The majority of respondents in Tongatapu reported spending less or the same amount of time on fishing trips now compared to when they started to fish, while 38.2% of respondents in Ha’apai reported spending more time on fishing trips now compared to when they started to fish. The majority of respondents in Tongatapu also reported that the size of the fish caught was the same or smaller now compared to when they started to fish. In Ha’apai, most of the respondents said that fish were smaller now compared to when they started to fish (Table II.5).

Table II.7. Comparison of fish catch, time spent fishing, and fish size from the time fishers started to fish to now (reported as percentage of respondents)*

	Tongatapu	Ha'apai
Fish catch then compared to now:		
More then	34.6	43.6
Same	11.5	14.5
Less then	50	38.2
Time spent fishing then compared to now:		
More then	36.5	25.5
Same	38.5	32.7
Less then	23.1	38.2
Size of fish caught then compared to now:		
Bigger then	36.5	34.5
Same	38.4	23.6
Smaller then	21.2	29.1

* Percentages do not add to 100% because respondents who did not answer the question (NA) are not included.

II.4 Discussion

The goal of this study was to examine if socioeconomic development affects small-scale fisheries. Using islands in the Kingdom of Tonga as a case study, we hypothesized that the more urbanized and westernized island, Tongatapu, would have greater resource exploitation than the less developed island, Ha’apai.

Even though the interviewees may not fully represent the entire population in both islands, our results suggest many interesting points. Our results confirmed our prediction that the cash exchange for finfish would be greater on Tongatapu, the more urbanized and developed island [23, 118]. In Ha’apai, where most fishing is for subsistence, over time fishers perceived a decrease in the amount of fish caught, an increase in the amount of time spent fishing, and a decrease in fish size, a typical case of overexploitation. Spearfishing is the preferred technique used on both islands, but fishers from Tongatapu use more boats in comparison to Ha’apai, and their fishing trips are longer (Table II.3). In Tongatapu, where most fish is harvested to be sold and fish markets are open daily [122], over time fishers perceived a increase in the amount of fish caught, a decreased or comparable time spent fishing, and a smaller fish size. Tongatapu perceived an increase in catch but a decrease in fish size, evidence of a classic relationship between economic development and environmental erosion [112]. Thus Tongatapu might suffer the effects of having an overexploited resource [119] faster than Ha’apai, especially because the demand for finfish increases with proximity to markets [18, 23].

Newton et al. [41] and Friedman et al. [93] reported that Tonga’s small-scale fisheries are collapsed. This status may be due to Tonga’s central management; policies are poorly implemented and fishery regulations are generally weakly enforced across the naturally scattered islands and reefs [2].

Small island nations such as the Kingdom of Tonga often struggle to be part of the global economy [112], which triggers unsustainable practices that contradict traditional resource extraction practices [123]. ”Open access” [108] means that the group using the natural resource is not well defined, and there are no rules or laws that restricting who can use the resources; consequently, the resources are more vulnerable to overexploitation [108] due to competition among users, which triggers unsustainable harvesting techniques [116]. Easter Island is the best example of how open access regimes can lead to collapsed resources [113]. On Tongatapu, there is no traditional form of management and conservation, and small-scale fisheries there are driven by an open-access system with cash-based exchanges for fish. At the other extreme, the customary tenure regime is very well defined by local rules and norms, and it has a controlled number of users [124].

An intermediate stage of resource exploitation is the open common access with an informal insurance system. In Ha'apai, marine resources are not controlled by locals [115] as in the traditional customary system; rather, it is open to anyone who wants to fish, as in open access systems. However, fishers participate in an "informal insurance system" [113] that works with a solidarity network [116]. In solidarity network systems, all members have "access to the vital resources, either through fishing grounds or through sharing of yields" [123]. This system, at least to a certain level, promotes sustainable resource use, since everyone is concerned with subsistence and fundamental needs. For example, there is only certain amount of fish a community can consume at a time, so there is no need to fish in large quantities; compared to fishers interested in selling their catch, who would want to catch more fish to generate more income.

Limitations

Even though interview-based studies of human resource use are important in assessing the sustainability of fisheries harvests, several factors that could affect the accuracy of the information must be considered. First, interviewees may misremember information due to the decay of memories over time [125]. Second, interviewees may have actively misled the interviewers [126]; for example, fishers may overestimate size of catch, a phenomenon that is well known to be part of fishing culture [127]. Third, as fish size and catch decreases in one location, fishers might change fishing grounds over time; also, changes (especially increases) in catch may be due to changes in fishing techniques. Neither of these phenomena were accounted for in our interview methodologies. Due to time constraints our surveys were only representative of 0.073% of the population in Tongatapu and 0.91% of the population in Ha'apai; a larger sample size may have altered our results.

Also, the surveys failed to account for environmental factors that may affect small-scale fisheries, such as pollution. For example, a 2006 study found that annual fertilizer use on Tongatapu (26,000 ha) has increased more than an order of magnitude since 1990 [112] due to the growth of squash exportation to Japan. Increased fertilizer use on land undoubtedly leads to more fertilizer runoff onto surrounding coral reefs, which may impact coral reef fisheries.

II.5 Conclusions

In Chapter I, small-scale fisheries in Tonga were defined as collapsed in a global report based on fish landings throughout tropical island nations. In this chapter, Tonga's small-scale fisheries were investigated in narrower view as a case study. Even though fishers from Ha'apai perceived a decrease in catch and size of the targeted fish over time, their exploitation demands are mostly for subsistence, which is far more sustainable than in Tongatapu. Targeted fish in Tongatapu have decreased in size; fishers here are fishing more to supply the demands of a more urbanized area, which indicates overexploitation. Consequently, Newton et al.'s [41] small-scale fisheries exploitation status can be applied to Tongatapu, the more developed island, but not to Ha'apai, the less developed island. As a matter of fact the different relationships with marine resources in two islands of the same archipelago reaffirms that studies of small-scale fisheries need to be more localized, rather than broad overviews as in [41], in order to more fully understand the causes of changes in fisheries production over time.

Appendix

Survey conducted in Tongatapu and Ha'apai in the year of 2012. Following [121] methods.

Household Survey

1. What is your age? ___________
2. Have you lived in this village your whole life? [ ] Yes [ ] No

If No

3. Where did you live before? ______________________
4. When did you move here? ______________________

If Yes

5. How long has your family (previous generations) lived here? ________________

FISHING EFFORT

6. What year did you start fishing? ___________
7. Do you still fish? [ ] Yes [ ] No

If no:

8. What year did you stop? _______ → ***Skip ahead to question #26.***

9. Do/Did you use a boat? [ ] yes [ ] no
10. What kind of boat? **Type:** ____________ **Length:**_______(meters); **Motor:** [ ] Y [ ] N
11. Are/Were you a [ ] boat owner or [ ] employee on a boat?

12. Within the past year, how many times per month did you fish by {...}?		13. When you fish by {...} what species do you try to catch?	14. When you fish by {...} what 3 species do you catch most?
Fishing type	**Frequency** **[ ] daily** **[ ] weekly** **[ ] monthly** **[ ] 1x per yr**	**Species targeted**	**Top species caught (list at least 3 species)**
Rod and reel			
Spear			
Invertebrate harvesting			
Handline			
Gill net			
Throw net			
Bamboo pole			
Other methods:___________			

15. Did you use different fishing methods when you **started**? [ ] Yes [ ] No

If Yes:

16. What fishing methods did you use then? ___________________________

17. Where do you fish? *(Check all that apply)* **[Show interviewee map]**
[ ] Your village [ ] Other villages: ____________ [ ] Unincorporated areas: ________________

18. Which part(s) of the reef do you fish? *(Check all that apply)*
[ ] Reef flat [ ] Reef slope [ ] Deep water
[ ] Lagoon [ ] Fresh water [ ] Other: _________

19. How important to you are the following reasons for fishing?

	Very important	Important	Somewhat important	Not important
To sell **				
To eat				
To give to friends and family				
Enjoy it/for fun				
Ceremonial / Celebration				
Other:				

*****If the respondent says <u>selling their catch is at all important</u> ask the questions in the box:***

20. Who or where do you sell your catch to? ____

21. Is fishing your primary source of income? [ ] Yes [ ] No

22. Could fishing provide enough income to support your household?
[ ] Yes, easily [ ] Yes, with difficulty [ ] Sometimes [ ] No [ ] Don't Know

If No:

23. Why not?
[ ] Couldn't catch enough [ ] Gear/fuel costs too much
[ ] Not enough people buying [ ] Other: _______________

24. How much did you rely on fishing for income when you started compared to now?

	Much more	More	Same	Less	Much less

25. Has the size of the fish you catch changed?

	Much more	More	Same	Less	Much less
Started fishing					

26. Has the amount of fish changed since you started fishing compared to now?

	Much more	More	Same	Less	Much less
Started fishing					

27. How much time did you spend fishing *(amount of time)* compared to now?

	Much more	More	Same	Less	Much less
Started fishing					

If answers "Same" → Skip to #35

TIES TO FISHING

28. Did your parents fish? [ ] Yes [ ] No [ ] Don't Know
29. Did your grandparents fish? [ ] Yes [ ] No [ ] Don't Know
30. Do you want your children to fish?
[ ] Yes [ ] No [ ] Don't Know [ ] Depends [ ] N/A

If No:

31. Why not? *(Check all that apply)*
[ ] Not a dependable source of income
[ ] Is difficult, physically demanding work
[ ] Is harder now than it was before
[ ] I want them to find a better job
[ ] Other: ________________________

If Yes:

32. Why? *(Check all that apply)*
[ ] It is a good source of income
[ ] It is a tradition in our family
[ ] Fishing is easy
[ ] They don't have other opportunities
[ ] Other: ______________________

33. How many people are in your household? ______
34. Who else in your household fishes or harvests invertebrates?

35. What are the other sources of income in your household?

DEMOGRAPHIC INFORMATION

36. Gender *(Don't ask, just mark the answer)*: [ ] Male [ ] Female

37. What is your religion/church?
[ ] Catholic [ ] Assembly of God [ ] Don't know
[ ] Methodist [ ] Jehovah's Witness [ ] None
[ ] Mormon [ ] Weslian Tongan's church [ ] Other: ___________
[ ] Bahá'i [ ] Seventh Day Adventist [ ] Prefer not to answer

38. What is your ethnicity? *(Check all that apply)*
[ ] Samoan [ ] Filipino [ ] Other Asian
[ ] Tongan [ ] Other Pacific Island [ ] Caucasian
[ ] Other:_________ [ ] Don't know [ ] Prefer not to answer

39. What is your combined household income range? Per month *(local currency)*
[ ] <$5,000 [ ] $10,001 - $15,000 [ ] >$25,000
[ ] $5,001 - $10,000 [ ] $15,001 - $25,000 [ ] Prefer not to answer

40. What is your educational background?
[ ] Less than elementary school [ ] University (4-year)
[ ] Elementary school [ ] Graduate school
[ ] High school [ ] Other: __________________
[ ] Community college (2 year) [ ] Prefer not to answer

41. Do you know of other fishers in your village who we should interview, and would you mind sharing their names and contact information?

Name	Location	Phone/email

42. Do you have any additional information or comments you would like to share?

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