

UC San Diego

UC San Diego Electronic Theses and Dissertations

Title

Fish, fishing, diving and the management of coral reefs

Permalink

<https://escholarship.org/uc/item/8cz488jh>

Author

Johnson, Ayana Elizabeth

Publication Date

2011

Peer reviewed|Thesis/dissertation

UNIVERSITY OF CALIFORNIA, SAN DIEGO

Fish, Fishing, Diving and the Management of Coral Reefs

A dissertation submitted in partial satisfaction of the
requirements for the degree Doctor of Philosophy

in

Marine Biology

by

Ayana Elizabeth Johnson

Committee in charge:

Professor Jeremy Jackson, Chair
Professor Theodore Groves
Professor Phillip Hastings
Professor Lisa Levin
Professor Stuart Sandin
Professor Jennifer Smith

2011

©

Ayana Elizabeth Johnson, 2011

All rights reserved

The Dissertation of Ayana Elizabeth Johnson is approved, and it is acceptable
in quality and form for publication on microfilm and electronically:

Chair

University of California, San Diego

2011

DEDICATION

for

Louise Elizabeth Maher-Johnson

my mother who walks the walk

TABLE OF CONTENTS

Signature Page	iii
Dedication	iv
Table of Contents	v
List of Figures	vi
List of Tables	vii
List of Graphs	viii
Acknowledgements	x
Vita	xi
Abstract of the Dissertation	xii
Introduction	1
Chapter 1: Trends, current understanding, and future directions for artisanal coral reef fisheries	5
Chapter 2: Reducing bycatch in coral reef trap fisheries: escape gaps as a step towards sustainability	35
Chapter 3: Moray eels as intelligent and abundant predators on Caribbean coral reefs	44
Chapter 4: Gill net use on Caribbean coral reefs is unsustainable	48
Chapter 5: Fishers, divers, and shifting baselines in artisanal coral reef fisheries: The old men of the sea and the Pollyannas	77
Chapter 6: Time preferences and the management of coral reef fisheries: discounting the future value of a dollar and a reef	118
Chapter 7: A socioeconomically informed approach to managing fishing and diving on Caribbean coral reefs	146
Appendix 1: Socioeconomic survey of fishers	178
Appendix 2: Socioeconomic survey of professional SCUBA divers	186

LIST OF FIGURES

Figure 2.1. Diagrams of the four types of fish traps used in this experiment	36
Figure 3.1. Green moray eels (<i>Gymnothorax funebris</i>) in fish traps in Curaçao	46
Figure 4.1. Bycatch and rare species caught and habitat damage caused by gill nets	65
Figure 5.1. Images of spearfishers' catches in Curaçao in 1960 and in 2009	102

LIST OF TABLES

Table 1.1. Attributes of two extreme scenarios of sustainable reef fisheries	25
Table 1.2. Types of journals and journal topics for coral reef fishery articles	25
Table 2.1. Market value and importance on Curaçao of reef fish families	37
Table 2.1. Results of ANOVAs testing for differences between trap types and locations ...	38
Table 2.3. Data for number, length, mass, and value of trapped fish	40
Table 4.1. Number, mass, and mean market value of species captured by gill nets	66
Table 4.2. Soak time, catch quantity, catch biomass, and catch value for all net sets	67
Table 4.3. Summary of gill net catch data presented in the peer-reviewed literature	68
Table 4.4. Species most desired and most frequently caught by gill net fishers	70
Table 4.5. Fisher and diver support for restricting gill net use	71
Table 4.6. Characteristics of gill net and fish trap catches on Curaçao	71
Table 5.1. Fisher anecdotes offered in response to interview questions	103
Table 5.2. Diver anecdotes offered in response to interview questions	105
Table 5.3. Demographics of fishers and divers interviewed on Curaçao and Bonaire	106
Table 5.4. Species mentioned by interviewees as now rarely seen or caught	107
Table 5.5. Mean interviewee gear scores, reserve scores, and conservation scores	107
Table 6.1. Price list switch points and their associated discount factors	137
Table 6.2. Demographics of fishers and divers interviewed on Curaçao and Bonaire	137
Table 6.3. Mean IDFs for fishers and divers with standard errors	138
Table 6.4. Mean interviewee gear scores, reserve scores, and conservation scores	138

LIST OF GRAPHS

Graph 1.1. Number of articles published annually on artisanal coral reef fisheries	26
Graph 1.2. Types of reef fisheries research presented in peer-reviewed articles	26
Graph 1.3. Categories of data presented in peer-reviewed articles on coral reef fisheries ...	27
Graph 1.4. Types of management recommendations made in peer-reviewed articles on coral reef fisheries	27
Graph 2.1. Mean catch composition of commonly caught families in each trap type	38
Graph 2.2. Mean number, length, mass, and market value of catches	39
Graph 4.1. Soak time versus number of fish captured in gill nets.....	72
Graph 4.2. CPUE of gill nets by year for all catches reported in the literature	72
Graph 5.1. Interviewee responses to questions about fish catch and coral reef health	108
Graph 5.2. Years of best and worst catches, and best year related to start year	109
Graph 5.3. Perceived changes in fish population in the last five years by age group	110
Graph 5.4. Perceived changes in catch by fishers interviewed in 1995 and 2009	110
Graph 5.5. Length and mass of lifetime-largest fish caught with various gears	111
Graph 5.6. Perceived causes of declines in fish populations	112
Graph 5.7. Perceived causes in catch declines by fishers interviewed in 1995 and 2009	112
Graph 6.1. Cumulative distributions of individual discount factors	139
Graph 6.2. Distributions of individual discount factors	140
Graph 6.3. Distributions of bias among fishers and divers	141
Graph 7.1. Management opinions of fishers and divers on Curaçao and Bonaire	169
Graph 7.2. Currently and formerly used types of fishing gear	170
Graph 7.3. Elasticity of fishing behaviors to fuel and fish prices	171
Graph 7.4. Interviewee perceptions of whether their profession is profitable	172
Graph 7.5. Interviewee perceptions of how long their professions will be profitable	172

Graph 7.6. Percentages of interviewees who support various gear restrictions	173
Graph 7.7. Percentages of interviewees who support various area restrictions	174
Graph 7.8. Percentages of interviewees who support various management measures	175

ACKNOWLEDGEMENTS

I would like to acknowledge Professor Jeremy Jackson, my advisor, for his guidance, trust, and support. I would also like to acknowledge Professor Stuart Sandin for inspiring the fish trap research that branched, diverged, and converged into this dissertation.

Chapter 1, in full, was submitted for publication of the material. Johnson, Ayana Elizabeth; Cinner, Joshua; Hardt, Marah; Jacquet, Jennifer; McClanahan, Tim; Sanchirco, James. The dissertation author was the primary investigator and author of this material.

Chapter 2, in full, is a reprint of the material as it appears in Marine Ecology Progress Series 2010. Johnson, Ayana Elizabeth. The dissertation author was the sole investigator and author of this material.

Chapter 3, in full, is currently being prepared for submission for publication of the material. Johnson, Ayana Elizabeth. The dissertation author was the sole investigator and author of this material.

Chapter 4, in full, was submitted for publication of the material. Johnson, Ayana Elizabeth. The dissertation author was the sole investigator and author of this material.

Chapter 5, in full, is currently being prepared for submission for publication of the material. Johnson, Ayana Elizabeth; Jackson, Jeremy B.C. The dissertation author was the primary investigator and author of this material.

Chapter 6 and Chapter 7, each in full, are currently being prepared for submission for publication of the material. Johnson, Ayana Elizabeth. The dissertation author was the sole investigator and author of this material.

VITA

2002	Bachelor of Arts, Harvard University
2002 - 2004	Environmental Scientist, U.S. Environmental Protection Agency
2009	Master of Science, University of California, San Diego
2011	Doctor of Philosophy, University of California, San Diego

PUBLICATIONS

Jacquet, J., Boyd I., Carlton J.T., Fox H., Johnson A.E., Mee L., Roman J., Spalding M., Sutherland, W.J. (2011) Scanning the oceans for solutions. *Solutions* 2(1): 46-55.

Johnson, A.E. (2010) Reducing bycatch in coral reef trap fisheries: escape gaps as a step towards sustainability. *Marine Ecology Progress Series* 415: 201-209.

Vermeij, M.J.A., Barott, K.L., Johnson, A.E., Marhaver, K.L. (2010) Release of eggs from tentacles in a Caribbean coral. *Coral Reefs* 29(2): 411.

West, J., Julius, S., Kareiva, P., Lawler, J.J., Enquist, C., Johnson, A.E., Shaw, M.R. (2009) Natural resources and climate change: a synthetic review of concepts and approaches for management adaptation. *Environmental Management* 44(6): 1001-1011.

Benham, C., Cawood, A.M., Cook, G.S., Darnell, A., Davison, P.C., Goldstein, M.C., Johnson, A.E., Konotchick, T., Maldonado, E.M., Pasulka, A.L., Prarie, J.C., Moseman, S.M., Tai, V., Tanner, C.A., Vardi, T., Whitty, T.S., Levin, L. (2008) Marine Metapopulations (Book Review). *Marine Ecology*, 29: 319-320.

ABSTRACT OF THE DISSERTATION

Fish, Fishing, Diving, and the Management of Coral Reefs

by

Ayana Elizabeth Johnson

Doctor of Philosophy in Marine Biology

University of California, San Diego, 2011

Professor Jeremy B. C. Jackson, Chair

This dissertation is a multi-disciplinary attempt to understand how coral reef resources can be managed sustainably. I begin by examining the peer-reviewed literature on artisanal reef fisheries, identifying gaps in knowledge, and proposing a set of priority areas for future research. Ecological examinations of trap fishing and gill nets follow. Fish trap bycatch can be dramatically reduced by the inclusion of escape gaps that allow juveniles and narrow-bodied species to escape, although catch of ecologically important herbivores remains high. Gill nets capture the few remaining apex predators present on Caribbean coral reefs, and as such their use is unsustainable. The second half of the dissertation is a tripartite presentation of the results of interviews with 177 fishers and 211 professional SCUBA divers on Curaçao and Bonaire. First, I consider whether interviewees' baseline conceptions of a healthy reef ecosystem is actually a degraded state, and they have a "shifting baseline." Then, I evaluate interviewees' discount rates and present bias, and relate those measures to their preferred management approaches. Lastly, I contemplate how to reconcile ecosystem requirements with stakeholder preferences, and employ socioeconomic information to develop a sustainable management plan.

INTRODUCTION

The overarching objective of my PhD research has been to examine options for the sustainable management of coral reef resources, using the islands of Curaçao and Bonaire as case studies. The two islands have similar coral reef ecosystems, strong fishing traditions, thriving dive tourism industries, and somewhat similar socio-political histories as former components of the Netherlands Antilles. Curaçao is in the formative stages of developing a plan to manage its marine resources, so it is the ideal time to assess the island's fisheries. In contrast, Bonaire has been actively managing its marine resources for decades with a marine park and fisheries regulations, and is internationally renowned for its conservation efforts and ethos. Both islands have experienced dramatic degradation of their coral reefs and fish populations in the last half-century. This dissertation focuses on fishing, and to a lesser extent SCUBA diving, and attempts to diagnose hindrances to sustainable resource use and suggest remedies for them.

Understanding the ecological effects of fishing on coral reefs can be quite complex as many species are harvested, many gear types are used, effort is spread among many boats, and the catch is landed at many ports. Dozens of fish species are commonly marketed, with groupers and snappers being the most desirable reef fish species. Gear types used include fish traps, hook-and-line bottom fishing, trolling, gill nets, beach seines, spearguns, and snorkel fishing.

My research began with a study of fish traps, inspired by the proposed regulation that would require use of escape gaps (Chapter 2). Trap fishing is relatively low effort as traps can be set one day and retrieved days later, but it generally yields lower value fish than other fishing methods, especially since the groupers they once commonly caught are now rare, and modern trap catches are dominated by herbivores, primarily parrotfish (Scaridae). During this research, I witnessed the high catch of herbivores and eels (Chapter 3), the potential ghost fishing impacts, and the high bycatch associated with traps. While escape gaps provide a low-cost and highly

effective way to reduce bycatch without reducing fishers' incomes, they do not remedy the other ills associated with trap use. Furthermore, trap fishing has declined substantially in recent years on both islands, partly because SCUBA divers commonly destroy traps, and some of the former trap fishing effort has shifted to gill nets.

Although gill nets are much maligned by divers and fishers alike, their use has been increasing in recent years. Gill nets are a passive gear normally set in five to fifteen meters of water to target nearshore pelagic species and reef fish. Bycatch is often quite high and habitat damage often substantial. Curaçao's fishery department has had a proposal for over a decade to ban their use in shallow water, but the political will to enact the legislation has yet to be amassed. In an attempt to provide policymakers with data on gill net catches that could inform their management plans, I worked with local gill net fishers to observe their fishing techniques and quantify their catches, and concluded that due primarily to catching the few remaining apex predators on the reef, gill net fishing is not sustainable (Chapter 4). It can be fairly straightforward to identify activities that are an inappropriate use of coral reefs; more complex is the challenge of determining how certain uses can be conducted appropriately. Herein, I focus on two uses – fishing and SCUBA diving – and attempt to meet that challenge.

The research I conducted on fishing gears aimed to support the efforts of resource managers who are working to improve the sustainability of their fisheries. Ultimately, however, managing fisheries is about managing human behavior, not about managing fish. Therefore, I wrestled with the socio-cultural dimension of fisheries. I conducted 238 socioeconomic interviews with fishers and professional SCUBA divers on Curaçao to gain insight into their perceptions of the state of the coral reefs and the fisheries. Because of the management insight I gleaned from these many conversations, I determined that conducting the same interviews on Bonaire, with its comparatively strong conservation record, would provide needed perspective and clarity. Collectively, the interviews from Curaçao plus the 150 conducted on Bonaire helped

me to understand the perspectives of fishers and divers as regards their expectations of ecosystem abundance and productivity, that is, whether their baselines have shifted towards considering a degraded state normal (Chapter 5).

In conducting the research on fishing gears it occurred to me that these fishing techniques were often only marginally profitable. I began to consider the economic determinants of fishing behaviors. This led me to the field of behavioral economics, and the concept of discount factors as a measure of the tradeoffs between present and future consumption of goods. For fishers, the goods are fish, which become money, so the research questions that I developed were whether fishers have similar conceptions of financial decisions and natural resource use decisions, how patient they are with both, how these metrics differ between fishers and divers, and what the implications of this are for sustainable management and incentivizing conservation. Thus, the interviews I conducted included questions that enabled me to calculate the discount rates of fishers and divers and relate their so-called time preferences to their resource management preferences (Chapter 6).

This collection of, perhaps seemingly disparate, projects has grown out of my desire to develop a holistic understanding of the complexities of coral reef management. At its root, this can be considered a simple problem: coral reefs are overfished – there are too many people and too few fish for harvest to continue at its present rate. But the details are important. Reef resources are critical to the welfare, nutrition, and cultural heritage of hundreds of millions of people, making it worthwhile to grapple with how to conserve both fish and fishing communities. There is a rich research history and broad literature on this topic. To synthesize this knowledge, I assembled a group of experts from ecology, sociology, and economics, to discuss what we know about artisanal coral reef fisheries, and perhaps more importantly, what we need to but do not yet know (Chapter 1). Integrating all these sources – fieldwork on fish traps and gill nets, socioeconomic interviews, time preference elicitation, and a review of the

literature – I put forth management recommendations for Curaçao and Bonaire (Chapter 7).

The case study presented here is not a unique case. Coral reef ecosystems colliding with fishing, tourism, development, and population growth are the norm. Hopefully, the fishing gear research, examination of fishers' and divers' shifted baselines, application of behavioral economics to coral reef management, identification of priorities for future research, management recommendations, and conclusions throughout this dissertation will be applicable to other islands and other resource management challenges, and will be applied.

CHAPTER 1:
Trends, current understanding, and future directions
for artisanal coral reef fisheries research

Abstract

Artisanal coral reef fisheries provide food and employment to hundreds of millions of people in developing countries, making their sustainability a priority for users, management, and research. Many of these fisheries are currently ecologically degraded and not yielding the full potential of socioeconomic returns. To help inform priority areas for future research, we present a literature review that evaluates past and current research effort and trends on coral reef fisheries. Our search of the peer-reviewed literature returned 364 articles, each of which was examined to identify the types of data presented and the types of management recommendations made. Main trends in the literature were a decline in experimental studies and in studies that report time series and fish catch biomass, density, and diversity, but an increase in papers containing stakeholder interview data. Management implications were discussed in 86% of articles and with increasing frequency over time, but only 25% of articles made management recommendations based on research presented in the article, as opposed to more general recommendations, such as the establishment of marine protected areas. We determine that key future research priorities are: (1) effectiveness of management approaches, (2) limits to sustainable extraction, (3) effects of climate change, (4) food security, (5) the role of aquaculture, (6) access to and control of fishery resources, (7) relationships between economic development and fishery exploitation, (8) alternative livelihoods, and (9) integration of ecological and socioeconomic research. Focusing on these areas will provide decision-makers with the necessary information to develop sustainable solutions.

Keywords: artisanal fisheries, coral reef fisheries, literature review, research priorities, small-scale fisheries, sustainable management

Introduction

The majority of fishing on coral reefs is artisanal, and despite its small-scale and low-tech nature, artisanal fishing is the major cause of the decline of reef fish populations (Newton et al., 2007). However, these fisheries also provide a critically important source of protein and employment for hundreds of millions of people in the developing world (Wilkinson, 2008, Paddock et al., 2009). On the global scale, an estimated 1.2 million artisanal fishers in the Caribbean and Americas, 0.98 million in Africa, and 6.1 million in Asia collectively catch an estimated 11.7 million tons of fish a year (Chuenpagdee and Pauly, 2008). Given this magnitude of catches, the associated environmental impacts, and the number of dependants, artisanal fisheries are an important economic sector and area of research.

Some attributes of artisanal fisheries, such as relatively low bycatch, low fossil fuel use, and high employment compared to industrial fisheries (Jacquet and Pauly, 2008), provide opportunities for producing environmentally sustainable catches, achieving low social cost, and increasing food security. Nevertheless, artisanal fishers have overexploited coral reef fisheries (Newton et al., 2007). Long-term time series are uncommon but the few that exist exhibit declines in the size and biomass of catches (McClenachan, 2009) associated with increasing fishing effort (Anticamara et al., 2011). Species composition within catches has also shifted – where predatory sharks, groupers and snappers once dominated landings, opportunistic and lower trophic level species have taken their places (Kaunda-Arara et al., 2003, Pandolfi et al., 2003, Bhathal and Pauly, 2008, McClanahan and Omukoto, in press). The reduction in catch quantity and change in catch composition, accompanied by declines in fish abundance and diversity, pose a problem for those people who depend on artisanal fisheries. However, trends of

increasing trophic level and value of catches have been demonstrated where effective management is in place (McClanahan, 2010).

Achieving sustainable fisheries is a challenge, particularly considering historical data show that relatively few fishers with fairly simple gear can rapidly deplete tropical coastal ecosystems (Jackson et al., 2001), especially reef fish (Wing and Wing, 2001). For example, in Jamaica, with a mean of only around two fishers per square kilometer, primarily using hook-and-line, the snapper and grouper populations were dramatically depleted in 200 years (Hardt, 2008, and M. J. Hardt, unpublished data). This pattern repeats itself throughout the Caribbean (Rick and Erlandson, 2008) and in tropical waters around the world (Dulvy et al., 2004, Pandolfi et al., 2005).

Not only can sustainable catch limits be exceeded with relative ease, but also in many locations those historical limits have been further depressed by the suite of modern impacts, including frequency of climate disturbances (Graham et al., 2007, Pistorius and Taylor, 2009). Add to that high levels of bycatch, habitat-damaging fishing gears such as fish traps, nets, and dynamite, and we have easily exceeded the thresholds of sustainable catch on most of the world's reefs. Fortunately, these impacts are not ubiquitous, inevitable, or irreversible. There are examples of reef fisheries where long-term changes have been small and difficult to detect (Dalzell, 1998, Craig et al., 2008), and where declining trends have been reversed by controlling fishing effort via culturally-sensitive management (McClanahan and Hicks, 2011).

Management of tropical fisheries is inherently complex, with many species caught by many gear types, and landed by many boats at many beaches and ports. The ways in which fishing communities interact with tropical resources are influenced by culture (Cinner and Aswani, 2007), and coral reefs are ecologically intricate. Consequently, for tropical fisheries to support fishers and their communities, management must include realistic ecological and socioeconomic constraints. Research to determine catch limits and to examine the cultural and

institutional contexts of sustainability are a critical priority for coral reef management and conservation programs. To promote increasingly sustainable management of artisanal reef fisheries, we briefly discuss definitions of sustainability, then examine and synthesize research trends, and highlight our recommended future research priorities.

Defining a sustainable fishery

In a simple ecological sense, a fishery can be defined as sustainable if a certain quantity and composition of catch can be removed repeatedly, when accounting for environmental fluctuations, over an extended period of time. This definition, however, can be problematic because highly degraded reef systems may produce a sustainable “weedy fishery” comprised of fast-growing, highly fecund, opportunistic species feeding low in the food web. Such fisheries can be highly resilient and sustain relatively high numbers of fishers (Table 1.1). For example, despite extremely high fishing pressure, some reefs in Kenya have produced the same yield ($\sim 16 \text{ Mg} \cdot \text{km}^{-2} \cdot \text{yr}^{-1}$) for more than 10 years, but 90% of that catch is comprised of fast growing and early maturing herbivorous fish (i.e. a trophic level ~ 2) approximately 12 cm long (McClanahan et al., 2008).

More holistic definitions of ecological sustainability require that the fishing occur without resulting in a decrease in the mean trophic level of the catch, the mean size of the target species, or the catch-per-unit-effort (CPUE), and without sequentially depleting sub-populations of stocks or impacting other species. An example of this is an “apex fishery” with few fishers and a high mean trophic level (i.e. average trophic level > 3.5) of catch. Apart from these two extremes of ‘weedy’ and ‘apex’ fisheries, there is expected to be an array of sustainable and unsustainable configurations – the latter being fisheries associated with habitat damage, high bycatch, and high catch of juveniles.

There are also varying degrees of socioeconomic sustainability, which includes dimensions such as maintaining the cultural fabric of a community versus transforming or undermining it, and on the economic side, engaging in managed or unmanaged economic growth. User groups often disagree upon how to prioritize and attain these dimensions of ecological and socioeconomic sustainability. For example, conservation-focused management goals and fishery-focused goals can be misaligned, each seeking to maintain very different aspects of fish and benthic populations. There are also important tradeoffs to consider between ecosystem services and employment – some ecologically sustainable fisheries will be incapable of financially sustaining a large number of fishers (Beddington et al., 2007). In many places, fishers may support an opportunistic configuration focused on high-turnover herbivores because it maximizes employment or the wealth of investors (McClanahan, 2010). In other cases, different fisheries might be at odds with one another. For example, tropical fish collection for the live reef food-fish trade removes fish from reef systems that other people depend upon for subsistence (Sadovy, 2005).

Literature review methodology

Understanding how artisanal fisheries affect coral reef ecosystems is a first step towards evaluating ecological sustainability and designing solutions for sustainable management. Consequently, this literature review assessed the current state and trends of research on artisanal reef fisheries, and identified gaps in knowledge. From this information, we suggest potential avenues for future research that could increase its applicability to effective management. We searched the literature using ISI Web of Knowledge, an online tool that searches over 10,000 natural and social science journals dating from 1899 to the present, to assemble an extensive list of peer-reviewed papers on this topic published through December 2010.

Searches on February 22nd, 2011 for “coral reef” plus “fisher*” produced 2,884 articles; “artisanal fish*” plus “coral” produced 120; and “small-scale fish*” (with and without the hyphen) plus “coral” produced 160. A search for “fisher*” plus “coral” plus “catch” produced 248 articles. Further searches conducted for commonly used gear types, “coral reef fish*” plus “spear,” “trap,” “net,” or “line,” collectively produced 496 articles. Use of the term “coral” largely restricted the results to coral reef fisheries, although searches did return some papers that also included catches in adjacent non-coral habitats such as seagrass and nearshore pelagic ecosystems. These papers, along with the few papers focused on invertebrate fisheries, were retained for inclusion in the analyses. Search results were combined, and the many duplicates, non-peer-reviewed papers (e.g. conference proceedings, reports), and articles outside our scope (e.g. temperate research) were removed after reading article titles and abstracts, for a total of 364 papers included in this study.

To parse the search results, each journal in which articles appeared was categorized as either a natural or social science journal. Those two categories were further subdivided into five journal types: biology and ecology, conservation science, fisheries science, policy and management, and economics and sociology. Each article was individually examined to identify the types of research conducted, types of data collected, and management recommendations made. Research was categorized as descriptive, modeling/theoretical, marine reserve research (i.e. fisheries closures), historical, experimental, or a review. Neither these categories nor the types of data and recommendations presented are mutually exclusive. Because a single paper can, for example, present an array of recommendations, the percentages presented here refer to the percentage of total papers having each of these attributes; thus the graphed percentages are absolute and do not sum to a hundred. To elucidate temporal trends in topic frequencies, logistic regressions against publication year were computed for each category of paper, type of data, and type of recommendation.

We did not include non-reef research papers, although we acknowledge that the results and recommendations therein may be applicable to reef fisheries. Further, we chose to exclude research conducted in the developed world (Australia, Japan, and USA) because fisheries there tend to be recreational or commercial rather than artisanal. Although we recognize that these locations have much to offer in terms of lessons for sustainability (McCook et al., 2010), we believe that the management and socioeconomic context are different enough to warrant their exclusion. We omitted a substantial amount of grey literature, and some relevant papers were not found because of limits to the search methodology. Also excluded from the analysis were findings discussed in book formats. Despite these limitations, the literature search provided a comprehensive investigation of the current body of research on artisanal coral reef fisheries.

Current research foci

Of the 364 peer-reviewed articles we identified on artisanal coral reef fisheries, the earliest study was published in 1982, and the number of articles published annually is rapidly increasing (Graph 1.1). The research covers a broad geographic area; the Southeast Asia/Indo-Pacific region was the most represented (166 articles), followed by Africa (73), the Caribbean (70), and the Eastern/Central Pacific (13). There were also 42 articles that synthesized information globally. The articles were published amongst 94 journals, although the vast majority (315 of the articles) appeared in natural science journals, with only 11 articles appearing in exclusively social or economic journals (Table 1.2). Nevertheless, it would be misleading to imply that this split represents the true distribution of research effort as many papers with social science components, including interviews with fishers, appeared in natural science journals.

Eighty percent of the research was descriptive and based on observations of the natural and social environment (Graph 1.2). Data were primarily collected using surveys of fish (both

underwater assessments and landings at docks), benthos, and fishers. Marine reserve research comprises 37% of the literature, modeling/theoretical papers 18%, and review papers 16%. Experimental research, such as testing the selectivity of various fishing gears or the effects of herbivore exclusions, was presented in 16% of all articles, and policy papers (those not presenting data, but rather focused on discussing management approaches) were uncommon, accounting for a mere 1.5% of articles. There has been a significant decline in the number of experimental papers published over time ($p = 0.032$), while temporal trends were not significant for the other article categories.

The three most frequently published types of data, each appearing in over one-third of papers, were the effects of fishing on fish communities, the taxonomic or functional diversity of fish communities or fish catches, and the density of the fish populations (Graph 1.3). The publication frequency of diversity, fish abundance, fish catch biomass, and fishing gear effect data have decreased significantly over time (all $p < 0.05$), as has the proportion of papers presenting time series data ($p = 0.009$). The only significant increasing trend ($p = 0.008$) is in the presentation of data from stakeholder interviews – from 2005 to 2010, 23% of published papers included such data. Papers that present data on fisher income, traditional ecological knowledge (TEK), bycatch, and mean trophic level of catch stand out for their rarity, with each category appearing in less than 4% of papers. This infrequency is despite the importance to fishery sustainability of minimizing bycatch, the usefulness of trophic level trends as an indicator of unsustainable fishing and/or management effectiveness, and the centrality of local knowledge and income to social palatability and the socioeconomic context of management.

Management *implications* were discussed in 86% of articles and they appeared with significantly increasing frequency over time ($p < 0.0001$); however, 30% of all papers did not make actual management *recommendations* (Graph 1.4). Of the 70% that did make recommendations, only 25% of those articles based their recommendations on options tested by

their research, as opposed to more general recommendations of options that were not measured. Marine reserves were the most commonly tested management option, followed by gear restrictions. Marine reserves were also the most commonly recommended management option, appearing in 47% of papers with no temporal trend in recommendation frequency. The two recommendations presented with significantly increasing frequency were co-management (where the government and communities collaborate on resource management; $p = 0.030$) and community-based management (where the community has management rights, including customary tenure systems and cooperatives; $p = 0.045$). The increasing trends were not due to the newness of the specific terms; all papers were examined for mention of those concepts, not the terms themselves. Implementing size restrictions and establishing property rights were the least common recommendations, both appearing in 4% of papers. Finally, though not a management recommendation per se, 55% of papers indicated a need for additional research and monitoring in order to devise more appropriate and more adaptive management strategies.

While marine reserves have received much natural science research attention, factors that may hinder compliance with marine reserves and other forms of fisheries management, such as level of community involvement (e.g. community-based management or co-management), availability of alternative livelihoods, and general alleviation of poverty, have received substantially less attention. While 11% of the articles recommend incorporation of alternative livelihoods into management plans, only 3% articles discussed the feasibility of real alternatives – aquaculture and direct payment for environmental services were mentioned (Barr and Mourato, 2009, Bell et al., 2009). Only 10% of the papers explicitly recommend a reduction in fishing effort (either the catch, the number of boats, the amount of gear, or the number of fishers), despite 95% of papers mentioning “overfishing” as a concern, a concern that has increased significantly over time ($p < 0.0001$). Other concerns commonly mentioned by researchers include population and demand growth (35%), development (27%), food security (20%), and

climate change (13%). Apart from development, all of these concerns were mentioned with significantly increasing frequency over time (all $p < 0.05$).

Future research priorities

We consider the shift towards investigations of socioeconomic context, users opinions, and management effectiveness, and the increased linkages of social and ecological research to be positive developments that could improve management and the chances for sustainability. Nevertheless, despite the rise in the number of papers on reef fisheries, many important questions remain unanswered. Given current research gaps revealed by this literature review, and our expertise, we suggest nine priority areas for future research into coral reef social-ecological systems:

(1) Ecological effectiveness of various management approaches

There are many management options available for artisanal reef fisheries, including spatial, temporal, effort, gear, species, and size restrictions. While these are often recommended and implemented, either individually or as part of a suite of regulations, the effectiveness of these restrictions is rarely tested. The exception is marine reserves, where researchers have examined the relationship between closure duration and fish population recovery (e.g., Russ and Alcala, 2004, McClanahan et al., 2007), compared fish and benthic communities inside and outside reserves (e.g., Russ and Alcala, 2004, Williamson et al., 2004), and identified trophic cascades following reserve establishment (e.g., Watson and Ormond, 1994).

Apart from marine reserves, a much more limited body of research has considered the effectiveness of various customary and community-based management frameworks (Cinner et al., 2005, McClanahan et al., 2006, Pollnac et al., 2010), models for determining optimal catches of fish from multiple trophic levels (Kramer, 2008, Kellner et al., 2011), and the potential effects

and benefits of gear restrictions (Johnson, 2010, McClanahan, 2010, Cinner et al., 2009c). A recent global meta-analysis identified strong leadership as the most important factor determining the success of fisheries management, and concluded that co-management is a promising management approach (Gutierrez et al., 2011). A similar study amalgamating such data specifically for the conditions under which coral reef co-management institutions are successful would be informative.

More research is needed on the wide variety of management approaches that have been conceptualized, modeled, and implemented (but less often tested) around the world, such as gear, species, and size restrictions, and the comparative effectiveness of various approaches to effort limitation. Few papers explicitly mention the need to reduce fishing effort, however that is necessary in many fisheries. Consequently, more studies are needed that evaluate the relative costs and benefits of various effort limitation strategies, such as limiting the number of fishers, boats, days at sea, types of gear, and total catch. A rigorous evaluation of the political ecology (who are the winners and who are the losers?) of these various approaches could greatly facilitate policymaker decision-making. Along these lines, the declining trends in experimental research and in the number of published time series is a concern; this trend should be reversed to improve evidence-based management and the testing of management hypotheses. Moderate and long-term (several years to decades) before and after studies can help determine whether theoretically effective management approaches actually achieve stated goals when implemented. Additionally, evaluating fishers' responses (i.e., altered fishing and economic behavior) to policy and management changes, and the synergistic effects of multiple policies is likely to increase the practicality of management (Smith et al., 2005).

(2) Thresholds, tradeoffs, and limits to extraction

Coral reef ecosystems are diverse and complex, with the potential of thresholds in ecosystem responses to stressors, and the possibility of trophic cascades and second order ecosystem effects (Bascompte et al., 2005). The dynamics of sea urchins and herbivorous fish grazing on calcifying algae in and out of marine reserves is one example of these second order effects (McClanahan et al., 1996). Such effects imply linkages across habitats and species that should be considered when developing spatial and temporal management (O'Leary and McClanahan, 2010).

While not all reef ecosystems have the same dynamics, research identifying general characteristics of sustainable reef catches that minimize, or at least account for, cascading or second orders effects on neighboring habitats or fisheries is urgently needed. There is little information for managers on the ecological limits to sustainability of multi-species tropical fisheries. For example, perhaps catch should be limited to a proportion of pristine biomass or current productivity, in order to prevent the system from surpassing thresholds and collapsing.

Research should also examine whether capturing certain species or functional groups, or capturing a certain ratio of trophic groups, will lead to the greatest fishery productivity, or whether productivity and fishing income is better maintained by capturing all groups in equal proportions (Kellner et al., 2011). Further, what is the best way to take advantage of the selectivity of fishing gear to achieve these goals (McClanahan and Cinner, 2008)? An interesting avenue for future research is to explore the ecological and economic costs, benefits, and tradeoffs of choosing a reef fishery reliant on a few fast growing species, versus an apex fishery that lightly uses more species but at lower fishing effort, versus fisheries that utilize closures of various percentage areas of the fishery. To compare these fisheries, it will be important to look at fish prices along with the fishing yields, costs of management, and tourism income (Hicks et al., 2009, McClanahan, 2010).

(3) Effects of climate change

The changing environment and climate warming are the context within which all other ecological factors operate. Elevated water temperature, acidification, and sea level rise may alter reproductive biology and growth rates in ways that could render classic models of coral reef population dynamics obsolete. Thus, the effects of climate change on artisanal reef fisheries need to be considered more explicitly. It is clear that climate change will affect organismal metabolic rates, ecosystem productivity, and species' ranges (Hoegh-Guldberg and Bruno, 2010), and will shift many fisheries poleward (Cheung et al., 2010). Recent research has begun to consider how acidification will decrease growth of calcifying organisms such as corals, bivalves, and other invertebrates (Kroeker et al., 2010); what the effects of coral bleaching might be on fisheries (Graham et al., 2007); and whether gear-based fisheries management could mitigate the effects of climate change (McClanahan and Mangi, 2004, Cinner et al., 2009c). While these studies represent important research advances, our understanding of how to manage fisheries in light of climate change remains rudimentary.

Expert coral reef fish biologists consider the ramifications of climate-induced habitat degradation to be a top research priority (Wilson et al., 2010). For example, reduced three-dimensionality of coral reef structure could reduce habitat and thereby increase predation rates on coral-dwelling fish species, thus changing food web dynamics (Coker et al., 2009). The effects of other changes are somewhat harder to predict, such as how climate change may influence fish recruitment, behavior, and population dynamics, and how management could augment resilience to such changes. Likewise, little is known about how changing environmental conditions may facilitate spread of disease and invasive species – factors critical to determining the health of fish communities. Laboratory studies on these topics have thus far focused not on food fish species, but rather on species whose physiology and high growth rate make them well-suited to laboratory research (Munday et al., 2009). Models of predicted environmental change,

coupled with laboratory studies of the responses of commercially important species to future conditions, would greatly aid managers' efforts to strategically plan for future scenarios.

(4) Food security

Globally, artisanal fisheries play a significant role in food security (Pauly, 2006). However, reef fisheries are highly susceptible to unsustainable fishing, potentially resulting in diminished long-term catches. In some cases, such as in coastal Kenya, heavily fished reefs sustain moderate yields of fast-growing herbivorous species, suggesting that even heavily fished reefs can play a role in food security (McClanahan et al., 2008), despite producing fewer monetary benefits than areas with more management restrictions (McClanahan, 2010). However, there are critical trade-offs between heavily and lightly fished reefs in the types of species caught (and their associated market value), and the ability of the system to provide other important ecosystem services. A critical area of research is determining the levels of fishing at which trade-offs with other ecosystem services become apparent, so that food security can be balanced with other ecosystem services and values.

(5) Aquaculture

Heavy reliance on wild fish for food is becoming less tenable in many coral reef countries because of rapidly growing human population size and an emerging middle class that can afford to eat more protein. Reefs may simply not be able to produce enough food to satisfy this growing demand, and there is a need to explore other ways to provide nutrition in a manner that does not further harm the ecosystem. Although still an area of debate, aquaculture, if carefully executed, may be able to fill this role and supplement fisheries' catches. Research has considered the feasibility of grouper aquaculture (Afero et al., 2010), the effects of algal farming on fish assemblages (Bergman et al., 2001), whether small-scale aquaculture can actually reduce

pressure on wild fish populations (Pomeroy et al., 2006), and the relationship between aquaculture and capture fisheries (Cruz-Trinidad et al., 2009). Although many currently used aquaculture techniques have a large environmental footprint, farming species low on the food chain, such as algae, filter and detritus-feeders, and herbivores has much promise (Duarte et al., 2009), as long as the species is native and/or unlikely to become invasive. Furthermore, possibilities for increasing efficiency and yields through polyculture (i.e. farming multiple species together, potentially reducing the need for inputs and reducing waste) remain largely unexplored, especially in coral reef ecosystems.

(6) Access to and control of fishery resources

Artisanal fisheries around the world face competition from both domestic and foreign industrial fishing boats. Many developing countries now export their fisheries resources, and some even sell off what they perceive to be ‘surplus’ fisheries production (often driven by reliance on incomplete statistics) and fishing rights to the developed world (Jacquet et al., 2010a). The lack of data on total fisheries catches, especially by the artisanal sector, can lead to over-licensing and under-patrolling. In sub-Saharan West Africa for example, foreign fishing nations’ payments for access agreements greatly under-represent the true value of the resource being extracted by foreign vessels from local Exclusive Economic Zones (EEZs; Kaczynski and Fluharty, 2002). Elsewhere in Africa, industrial shrimp trawlers skirt laws that designate inshore fishing areas for artisanal fishers. The trawlers damage passive gears set by the artisanal fisheries, destroy bottom habitat, and produce high levels of bycatch (Marquette et al., 2002, Jacquet et al., 2010a).

Assigning property rights to artisanal fishers has the potential to increase resource stewardship and thereby fishery sustainability if the rights can be enforced and equitably distributed (Gelcich et al., 2010). In this vein, articles have explored successes (Zann, 1999,

Pollnac et al., 2001a, Gutierrez et al., 2011) and enforcement challenges (Baticados and Agbayani, 2000) of co-management, and the need for legislation to legitimize community-based management and customary resource tenure (Aswani and Sabetian, 2010, Clarke and Jupiter, 2010). Excluding foreign fishing and creating priority inshore zones for artisanal fishers (Alcala and Russ, 2006, Jacquet et al., 2010a) are possible management options that have not been widely explored or implemented.

Property rights can be implemented through various frameworks, including cooperatives, individual transferable quotas (ITQs), and territorial use rights in fisheries (TURFs). It should be noted that such approaches are not universally successful, for example the cooperative movement of the 1980s (Sievanen et al., 2005); however establishment of property rights has the potential to improve control of resources and improve or stabilize income for fishers. Research is needed to determine which approaches produce the greatest ecological and social benefits while simultaneously encouraging voluntary compliance (Pollnac et al., 2010), and how property rights could be most effectively allocated and enforced (Gelcich et al., 2010). Following on this, there is a need for research on how the benefits of property rights can be further enhanced by employing alternative business structures such as increased local branding of resources, and increased vertical integration of artisanal fishers into marketing and processing via cooperatives. Community supported fisheries (based on the community supported agriculture (CSA) model), where consumers pay in advance each season for a portion of the catch, are one potential approach (www.walking-fish.org).

(7) Relationships between economic development and resource exploitation

Although the literature recognizes development as a significant concern for fishery sustainability, the dynamics of the relationships between poverty, infrastructure, ease of access to markets, and fishing behavior are only just starting to be explored (Cinner et al., 2009a,

Cinner et al., 2009b, Schmitt and Kramer, 2009, Bene et al., 2010). Researchers have examined how resource depletion can be influenced by distance to markets (Cinner and McClanahan, 2006, Brewer et al., 2009), transportation infrastructure (Liese et al., 2007, Schmitt and Kramer, 2009), urbanization (Aswani and Sabetian, 2010), and human population size (Cinner and McClanahan, 2006, Stallings, 2009). Yet, many of these studies have been statistical correlations and there is a need to better understand the causal mechanisms through which development affects the use of coral reef resources.

Future research needs to shed light on how other aspects of development, such as building roads and schools, can dampen or reinforce fishing behaviors (Cinner et al., 2011). The ramifications of exporting fish to major markets, as opposed to retaining catches for local and subsistence consumption, is also inadequately studied as pertains to incentives for overexploitation and the types of species targeted. A better understanding is required of the degree to which resource conservation in developed countries can result in heavier resource exploitation in poor, less-regulated developing countries through international demand. Critical to this will be fostering mechanisms to prevent the shifting of environmental footprints from wealthy countries that can afford to implement strict conservation policies to poorer countries with fewer environmental controls (Arrow et al., 1995, Cinner et al., 2009b).

(8) Alternative livelihoods

Where sustainability requires reductions in the number of fishermen, it becomes important to consider alternative employment for those who cannot continue to fish. Aquaculture is an oft-suggested option. While it is tempting to consider aquaculture and alternative livelihoods in the same breath, experience shows the effectiveness of substituting aquaculture jobs for fishing jobs to be highly variable (Sievanen et al., 2005). It is not enough that they are both water-based livelihoods. The psycho-cultural preferences of fishers for aggressive,

adventurous, and dangerous activities (Pollnac and Poggie, 2008) often make them unsuited for the nurturing, routine, and comparatively dull life of an aquaculturist. Furthermore, because fishing is typically a lifestyle choice in addition to a job, it is important to understand how the introduction of alternative livelihoods will dampen or reinforce fishing behaviors (Cinner et al., 2011).

This lifestyle aspect of fishing can influence both the point at which fishers decide to seek alternative employment and their perspectives on management approaches such as marine reserves (Smith et al., 2010). Alternative income sources may not reduce fishing pressure in the absence of restrictions that limit fishing effort, because formerly professional fishers may simply become recreational fishers. Furthermore, alternative incomes can create indirect pressures on reef ecosystems through coastal development, changes to land use patterns, and changes to demand. For example, growth of the tourism industry often results in increased coastal development and increased demand for locally caught seafood. Future research should focus on improving our understanding of the non-economic dimensions of dependence on fishing, including identity, satisfaction, tradition, and gastronomic preferences (Pollnac et al., 2001b, Pollnac and Poggie, 2006).

When developing alternative livelihood opportunities, the gender-specific nature of employment in many cultures should be taken into account. For example, weaving baskets for the tourist market, or other jobs in the tourist industry, may not be culturally viable alternatives for a fisherman. Such jobs could however be a means of diversifying household incomes. Another interesting area includes understanding the role of women (e.g. West Africa) or absence of women (e.g. Ecuador) in the sale of seafood caught by artisanal fisheries and the impact of that role on households (e.g., food security, child education). There are also social, psychological, and cultural constraints to adopting alternative livelihoods. All this points to a

need for case studies of successes and failures to take a systematic approach to reporting so that meta-analyses can be conducted and broad lessons learned.

(9) Integrating ecological and socioeconomic research

Above all, a more holistic view of artisanal fisheries management that further integrates ecological, social, economic, and institutional considerations is expected to lead to improved sustainability (Hughes et al., 2005). Taking a broad interdisciplinary perspective allows researchers to consider the socioeconomic drivers of unsustainable fishing (Cinner and McClanahan, 2006), the market forces driving unsustainable levels of consumption (Jacquet et al., 2010b), and the success of various coral reef management techniques (Pollnac et al., 2001a, McClanahan et al., 2006, Pollnac et al., 2010), in addition to the ecological dynamics of the system. Each approach to limiting fishing effort has socioeconomic as well as ecological implications. For example, recent research has shown that applying financial portfolio theory to ecosystem-based fisheries management can increase fishery revenues and decrease catch variance (Sanchirico et al., 2008). Taking an even broader view of household and community economic portfolios is expected to produce greater insights into the factors that influence fishery sustainability.

There are win-win situations for fishers and reef ecosystems associated with no-take marine reserves (Kellner et al., 2011), bycatch reduction (Johnson, 2010), and value-added fishery products, and these should be explored and exploited where they are found. However, such situations are not the norm, making it important for integrated research to explicitly consider the tradeoffs between ecological and socioeconomic benefits. In this manner, losses can be minimized and resource managers can be provided with useful data to inform their decisions and demonstrate benefits to the community. If the goal is to find optimal solutions for both the fish and the fishers – which we believe sustainable solutions must do – an even greater focus on

socioeconomic aspects of artisanal fisheries is required. And most broadly, we must grapple with how to structure incentives for sustainable resource use, such as via property-rights for fishers, and how to bring short-term human needs in line with long-term conservation goals.

It is important to note that socially successful (i.e. well-supported by the community) management can accompany overexploitation. In other words, ecological thresholds for sustainable resource use can temporarily be exceeded even while fishers continue to profit and a healthy social structure remains intact (Steneck et al., in press). There are both ecological and socioeconomic thresholds, tradeoffs, and limits associated with all management options. Consequently, we challenge scientists to engage in multi-disciplinary research initiatives that can critically inform the management process, and to present the potential ecological, social, and economic benefits and costs of regulatory options. Furthermore, it is not enough to simply do the research; researcher expertise and research outputs need to connect with decision-makers at all levels to help them make more informed decisions. From this, a more strategic and collaborative approach, focused on the drivers of fishing, can emerge to guide sustainable management and help ensure the future of coral reef fish and fisheries.

Acknowledgments

This paper is the outgrowth of a 2010 AAAS conference symposium entitled “Limits to the Sustainability of Coral Reef Fisheries,” which was organized by A.E.J., and in which all co-authors participated. J.B.C. Jackson, S. Sandin, S. Smith, L. Levin, and T. Groves provided helpful comments on earlier drafts.

Chapter 1, in full, was submitted for publication of the material. Johnson, Ayana Elizabeth; Cinner, Joshua; Hardt, Marah; Jacquet, Jennifer; McClanahan, Tim; Sanchirco, James. The dissertation author was the primary investigator and author of this material.

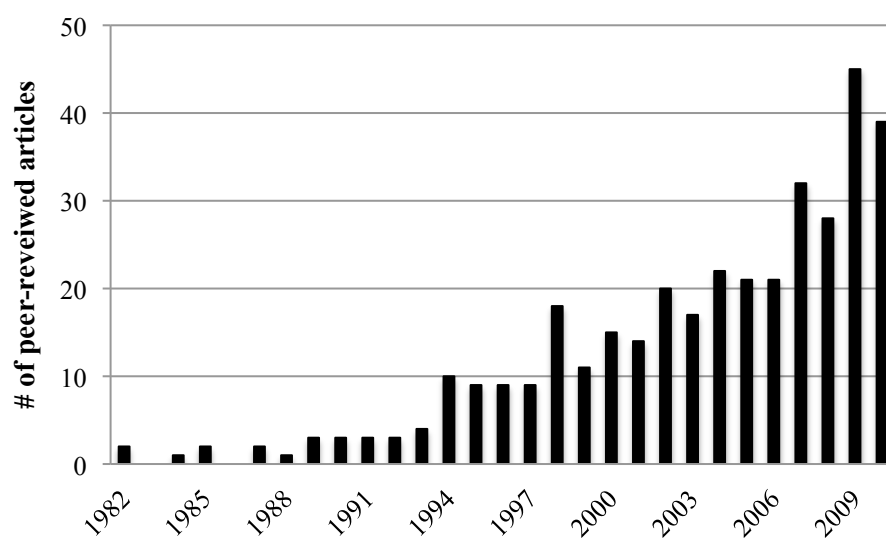
Table 1.1. Attributes of two extreme scenarios of sustainable reef fisheries.

Metric	Apex Reef Fishery	Opportunistic Reef Fishery
biodiversity	high	low to moderate
standing biomass	high	low
biomass harvested	low	high
target species	K-selected, climax species	r-selected, fast-growing species
mean trophic level	higher (predator dominated)	lower (herbivore dominated)
gears used	selective (hook-and-line)	unselective (nets and traps)
CPUE	high	low to moderate
# fishers	low	high
fisher income	high	low

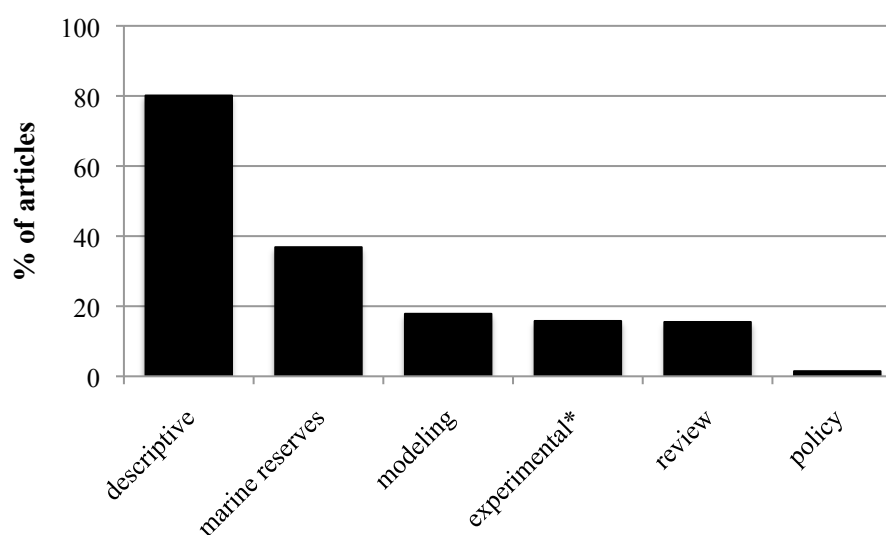
Table 1.2. Types of journals and journal topics for the 364 artisanal reef fishery articles retrieved by an ISI Web of Knowledge literature search on February 22nd, 2011.

Journal type	General journal topic	# of articles
natural science	biology and ecology	145
	conservation science	119
	fisheries science	51
social science	policy and management	38
	economics and sociology	11

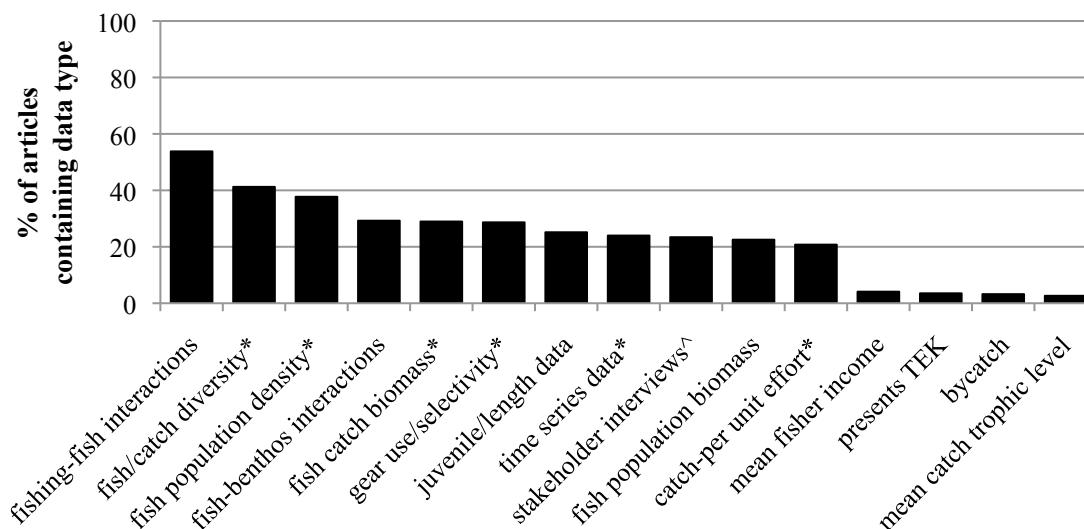
Graph 1.1. Number of articles on artisanal coral reef fisheries published annually in peer-reviewed journals through February 22nd, 2011.



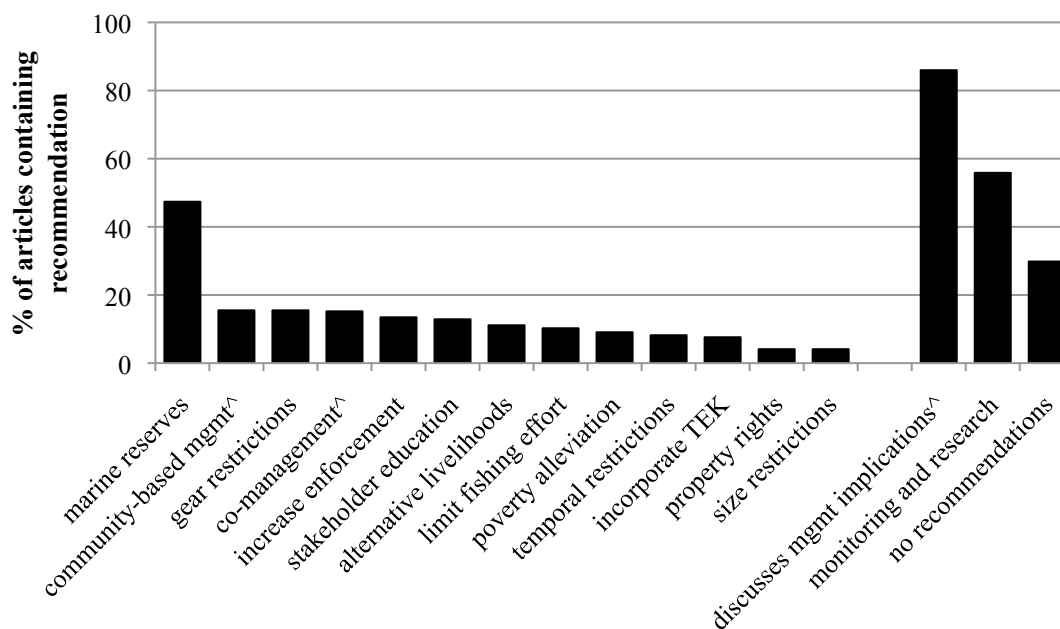
Graph 1.2. Types of artisanal reef fisheries research presented in peer-reviewed articles published through February 22nd, 2011. Asterisk denotes a declining trend in the absolute frequency with which experimental papers appear in the literature ($p = 0.009$).



Graph 1.3. Frequencies of data categories presented in peer-reviewed artisanal coral reef fisheries articles published through February 22nd, 2011. TEK stands for traditional ecological knowledge. Data types with significantly increasing or decreasing trends in the frequency with which they appear in the literature are denoted by ^ and * respectively (all $p < 0.05$).



Graph 1.4. Frequencies of management (abbreviated as “mgmt”) recommendations made in peer-reviewed artisanal coral reef fisheries articles published through February 22nd, 2011. Recommendations with significantly increasing trends in the frequency with which they appear in the literature are denoted by ^ (all $p < 0.05$). There were no significant decreasing trends.



References

- Afero, F., Miao, S., Perez, A.A. (2010) Economic analysis of tiger grouper *Epinephelus fuscoguttatus* and humpback grouper *Cromileptes altivelis* commercial cage culture in Indonesia. *Aquaculture International* **18**.
- Alcala, A.C., Russ, G.R. (2006) No-take Marine Reserves and Reef Fisheries Management in the Philippines: A New People Power Revolution. *AMBIO: A Journal of the Human Environment* **35**, 245-254.
- Anticamara, J.A., Watson, R., Gelchu, A., Pauly, D. (2011) Global fishing effort (1950-2010): Trends, gaps, and implications. *Fisheries Research* **107**, 131-136.
- Arrow, K., Bolin, B., Constanza, R., *et al.* (1995) Economic Growth, Carrying Capacity, and the Environment. *Science* **268**, 520-521.
- Aswani, S., Sabetian, A. (2010) Implications of Urbanization for Artisanal Parrotfish Fisheries in the Western Solomon Islands. *Conservation Biology* **24**, 520-530.
- Barr, R.F., Mourato, S. (2009) Investigating the potential for marine resource protection through environmental service markets: An exploratory study from La Paz, Mexico. *Ocean & Coastal Management* **52**, 568-577.
- Bascompte, J., Melian, C.J., Sala, E. (2005) Interaction strength combinations and the overfishing of a marine food web. *Proceedings of the National Academy of Sciences of the United States of America* **102**, 5443-5447.
- Baticados, D.B., Agbayani, R.F. (2000) Co-management in marine fisheries in Malalison Island, central Philippines. *International Journal of Sustainable Development and World Ecology* **7**, 343-355.
- Beddington, J.R., Agnew, D.J., Clark, C.W. (2007) Current problems in the management of marine fisheries. *Science* **316**, 1713-1716.
- Bell, J.D., Clua, E., Hair, C.A., Galzin, R., Doherty, P.J. (2009) The capture and culture of post-larval fish and invertebrates for the marine ornamental trade. *Reviews in Fisheries Science* **17**, 223-240.
- Bene, C., Hersoug, B., Allison, E.H. (2010) Not by rent alone: Analysing the pro-poor functions of small-scale fisheries in developing countries. *Development Policy Review* **28**, 325-358.
- Bergman, K.C., Svensson, S., Ohman, M.C. (2001) Influence of algal farming on fish assemblages. *Marine Pollution Bulletin* **42**, 1379-1389.
- Bhathal, B., Pauly, D. (2008) 'Fishing down marine food webs' and spatial expansion of coastal fisheries in India, 1950-2000. *Fisheries Research* **91**, 26-34.

- Brewer, T.D., Cinner, J.E., Green, A., Pandolfi, J.M. (2009) Thresholds and multiple scale interaction of environment, resource use, and market proximity on reef fishery resources in the Solomon Islands. *Biological Conservation* **142**, 1797-1807.
- Cheung, W.W.L., Lam, V.W.Y., Sarmiento, J.L., *et al.* (2010) Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. *Global Change Biology* **16**, 24-35.
- Chuenpagdee, R., Pauly, D. (2008) Small is beautiful? A database approach for global assessment of small-scale fisheries: Preliminary results and hypotheses. *American Fisheries Society Symposium* **49**, 575-583.
- Cinner, J., Aswani, S. (2007) Integrating customary management into marine conservation. *Biological Conservation* **140**, 201-216.
- Cinner, J.E., Daw, T., McClanahan, T.R. (2009a) Socioeconomic factors that affect artisanal fishers' readiness to exit a declining fishery. *Conservation Biology* **23**, 124-130.
- Cinner, J.E., Folke, C., Daw, T., Hicks, C.C. (2011) Responding to change: Using scenarios to understand how socioeconomic factors may influence amplifying or dampening exploitation feedbacks among Tanzanian fishers. *Global Environmental Change* **21**, 7-12.
- Cinner, J.E., Marnane, M.J., McClanahan, T.R. (2005) Conservation and community benefits from traditional coral reef management at Ahus Island, Papua New Guinea. *Conservation Biology* **19**, 1714-1723.
- Cinner, J.E., McClanahan, T.R. (2006) Socioeconomic factors that lead to overfishing in small-scale coral reef fisheries of Papua New Guinea. *Environmental Conservation* **33**, 73-80.
- Cinner, J.E., McClanahan, T.R., Daw, T.M., *et al.* (2009b) Linking social and ecological systems to sustain coral reef fisheries. *Current Biology* **19**, 206-212.
- Cinner, J.E., McClanahan, T.R., Graham, N.A.J., Pratchett, M.S., Wilson, S.K., Raina, J.B. (2009c) Gear-based fisheries management as a potential adaptive response to climate change and coral mortality. *Journal of Applied Ecology* **46**, 724-732.
- Clarke, P., Jupiter, S.D. (2010) Law, custom and community-based natural resource management in Kubulau District (Fiji). *Environmental Conservation* **37**, 98-106.
- Coker, D.J., Pratchett, M.S., Munday, P.L. (2009) Coral bleaching and habitat degradation increase susceptibility to predation for coral-dwelling fishes. *Behavioral Ecology* **20**, 1204-1210.
- Craig, P., Green, A., Tuilagi, F. (2008) Subsistence harvest of coral reef resources in the outer islands of American Samoa: Modern, historic and prehistoric catches. *Fisheries Research* **89**, 230-240.

- Cruz-Trinidad, A., Geronimo, R.C., Alino, P.M. (2009) Development trajectories and impacts on coral reef use in Lingayen Gulf, Philippines. *Ocean & Coastal Management* **52**, 173-180.
- Dalzell, P. (1998) The role of archaeological and cultural-historical records in long-range coastal fisheries resources management strategies and policies in the Pacific Islands. *Ocean and Coastal Management* **40**, 237-252.
- Duarte, C.M., Holmer, M., Olsen, Y., *et al.* (2009) Will the oceans help feed humanity? *BioScience* **59**, 967-976.
- Dulvy, N.K., Freckleton, R.P., Polunin, N.V.C. (2004) Coral reef cascades and the indirect effects of predator removal by exploitation. *Ecology Letters* **7**, 410-416.
- Gelcich, S., Hughes, T.P., Olsson, P., *et al.* (2010) Navigating transformations in governance of Chilean marine coastal resources. *Proceedings of the National Academy of Sciences* **107**, 16751-17060.
- Graham, N.A.J., Wilson, S.K., Jennings, S., *et al.* (2007) Lag effects in the impacts of mass coral bleaching on coral reef fish, fisheries, and ecosystems. *Conservation Biology* **21**, 1291-1300.
- Gutierrez, N.L., Hilborn, R., Defeo, O. (2011) Leadership, social capital and incentives promote successful fisheries. *Nature* **470**, 386-389.
- Hardt, M.J. (2008) Lessons from the past: the collapse of Jamaican coral reefs. *Fish and Fisheries* **10**, 143-158.
- Hicks, C.C., McClanahan, T.R., Cinner, J.E., Hills, J.M. (2009) Trade-offs in values assigned to ecological goods and services associated with different coral reef management strategies. *Ecology and Society* **14**, 18pp.
- Hoegh-Guldberg, O., Bruno, J.F. (2010) The impact of climate change on the world's marine ecosystems. *Science* **328**, 1523-1528.
- Hughes, T., Bellwood, D., Folke, C., Steneck, R., Wilson, J. (2005) New paradigms for supporting the resilience of marine ecosystems. *Trends in Ecology & Evolution* **20**, 380-386.
- Jackson, J.B.C., Kirby, M.X., Berger, W.H., *et al.* (2001) Historical overfishing and the recent collapse of coastal ecosystems. *Science* **293**, 629-638.
- Jacquet, J., Fox, H., Motta, H., Ngusaru, A., Zeller, D. (2010a) Few data but many fish: marine small scale fisheries catches for Mozambique and Tanzania. *African Journal of Marine Science* **32**, 97-106.
- Jacquet, J., Hocevar, J., Lai, S., *et al.* (2010b) Conserving wild fish in a sea of market-based efforts. *Oryx* **44**, 45-56.

- Jacquet, J., Pauly, D. (2008) Funding priorities: Big barriers to small-scale fisheries. *Conservation Biology* **22**, 832-835.
- Johnson, A.E. (2010) Reducing bycatch in coral reef trap fisheries: escape gaps as a step towards sustainability. *Marine Ecology Progress Series* **415**, 201-209.
- Kaczynski, V.M., Fluharty, D. (2002) European policies in West Africa: who benefits from fisheries agreements? *Marine Policy* **26**, 74-93.
- Kaunda-Arara, B., Rose, G.A., Muchiri, M.S., Kaka, R. (2003) Long-term trends in coral reef fish yields and exploitation rates of commercial species from coastal Kenya. *Western Indian Ocean Journal of Marine Science* **2**, 105-116.
- Kellner, J.B., Sanchirico, J.N., Hastings, A., Mumby, P.J. (2011) Optimizing for multiple species and multiple values: tradeoffs inherent in ecosystem-based fisheries management *Conservation Letters* **4**, 21-30.
- Kramer, D.B. (2008) Adaptive harvesting in a multiple-species coral-reef food web. *Ecology and Society* **13**.
- Kroecker, K.J., Kordas, R.L., Crim, R.N., Singh, G.G. (2010) Meta-analysis reveals negative yet variable effects of ocean acidification on marine organisms. *Ecology Letters* **13**, 1419-1434.
- Liese, C., Smith, M.D., Kramer, R.A. (2007) Open access in a spatially delineated artisanal fishery: the case of Minahasa, Indonesia. *Environment and Development Economics* **12**, 123-143.
- Marquette, K.M., Koranteng, K.A., Overa, R., Aryeetey, G. (2002) Small-scale fisheries, population dynamics, and resource use in Africa: the case of Moree, Ghana. *Ambio* **31**, 324-336.
- McClanahan, T.R. (2010) Effects of fisheries closures and gear restrictions on fishing income in a Kenyan coral reef. *Conservation Biology* **24**, 1519-1528.
- McClanahan, T.R., Cinner, J.E. (2008) A framework for adaptive gear and ecosystem-based management in the artisanal coral reef fishery of Papua New Guinea. *Aquatic Conservation-Marine and Freshwater Ecosystems* **18**, 493-507.
- McClanahan, T.R., Graham, N.A.J., Calnan, J.M., MacNeil, M.A. (2007) Toward pristine biomass: Reef fish recovery in coral reef marine protected areas in Kenya. *Ecological Applications* **17**, 1055-1067.
- McClanahan, T.R., Hicks, C.C. (2011) Changes in life history and ecological characteristics of coral reef fish catch composition with increasing fishery management. *Fisheries Management and Ecology* **18**, 50-60.
- McClanahan, T.R., Hicks, C.C., Darling, E.S. (2008) Malthusian overfishing and efforts to overcome it on Kenyan coral reefs. *Ecological Applications* **18**, 1516-1529.

- McClanahan, T.R., Kamukuru, A.T., Muthiga, N.A., Yebio, M.G., Obura, D. (1996) Effect of sea urchin reductions on algae, coral, and fish populations. *Conservation Biology* **10**, 136-154.
- McClanahan, T.R., Mangi, S.C. (2004) Gear-based management of a tropical artisanal fishery based on species selectivity and capture size. *Fisheries Management and Ecology* **11**, 51-60.
- McClanahan, T.R., Omukoto, J.O. (in press) Comparing modern fish catch in fisheries closures and open-access fishing grounds with historical catches (AD 750-1400) in Kenya. *Conservation Biology*.
- McClanahan, T.R., Verheij, E., Maina, J. (2006) Comparing the management effectiveness of a marine park and a multiple-use collaborative fisheries management area in East Africa. *Aquatic Conservation-Marine and Freshwater Ecosystems* **16**, 147-165.
- McClenachan, L. (2009) Documenting loss of large trophy fish from the Florida Keys with historical photographs. *Conservation Biology* **23**, 636-643.
- McCook, L.J., Ayling, T., Cappo, M., *et al.* (2010) Adaptive management of the Great Barrier Reef: A globally significant demonstration of the benefits of networks of marine reserves. *Proceedings of the National Academy of Sciences of the United States of America* **107**, 18278-18285.
- Munday, P.L., Donelson, J.M., Dixon, D.L., Endo, G.G.K. (2009) Effects of ocean acidification on the early life history of a tropical marine fish. *Proceedings of the Royal Society B: Biological Sciences* **276**, 3275-3283.
- Newton, K., Cote, I.M., Pilling, G.M., Jennings, S., Dulvy, N.K. (2007) Current and future sustainability of island coral reef fisheries. *Current Biology* **17**, 655-658.
- O'Leary, J.K., McClanahan, T.R. (2010) Trophic cascades result in large-scale coralline algae loss through differential grazer effects. *Ecology* **91**, 3584-3597.
- Paddack, M.J., Reynolds, J.D., Aguilar, C., *et al.* (2009) Recent region-wide declines in Caribbean reef fish abundance. *Current Biology* **19**, 590-595.
- Pandolfi, J.M., Bradbury, R.H., Sala, E., *et al.* (2003) Global trajectories of the long-term decline of coral reef ecosystems. *Science* **301**, 955-958.
- Pandolfi, J.M., Jackson, J.B.C., Baron, N., *et al.* (2005) Ecology - Are US coral reefs on the slippery slope to slime? *Science* **307**, 1725-1726.
- Pauly, D. (2006) Major trends in small-scale marine fisheries, with emphasis on developing countries, and some implications for the social sciences. *Maritime Studies* **4**, 7-22.
- Pistorius, P.A., Taylor, F.E. (2009) Declining catch rates of reef fish in Aldabra's marine protected area. *Aquatic Conservation: Marine and Freshwater Ecosystems* **19**, S2-S9.

- Pollnac, R., Christie, P., Cinner, J.E., *et al.* (2010) Marine reserves as linked social–ecological systems. *Proceedings of the National Academy of Sciences* **107**, 18262-18265.
- Pollnac, R.B., Crawford, B.R., Gorospe, M.L.G. (2001a) Discovering factors that influence the success of community-based marine protected areas in the Visayas, Philippines. *Ocean & Coastal Management* **44**, 683-710.
- Pollnac, R.B., Poggie, J.J. (2006) Job satisfaction in the fishery in two southeast alaskan towns. *Human Organization* **65**, 329-339.
- Pollnac, R.B., Poggie, J.J. (2008) Happiness, well-being and psychocultural adaptation to the stresses associated with marine fishing. *Human Ecology Review* **15**, 194-200.
- Pollnac, R.B., Pomeroy, R.S., Harkes, I.H.T. (2001b) Fishery policy and job satisfaction in three southeast Asian fisheries. *Ocean & Coastal Management* **44**, 531-544.
- Pomeroy, R.S., Parks, J.E., Balboa, C.M. (2006) Farming the reef: is aquaculture a solution for reducing fishing pressure on coral reefs? *Marine Policy* **30**, 111-130.
- Rick, T.C., Erlandson, J.M. (2008) Human Impacts on Ancient Marine Ecosystems: A Global Perspective. University of California Press, Berkeley, CA, p. 319.
- Russ, G.R., Alcala, A.C. (2004) Marine reserves: long-term protection is required for full recovery of predatory fish populations. *Oecologia* **138**, 622-627.
- Sadovy, Y. (2005) Trouble on the reef: the imperative for managing vulnerable and valuable fisheries. *Fish and Fisheries* **6**, 167-185.
- Sanchirico, J.N., Smith, M.D., Lipton, D.W. (2008) An empirical approach to ecosystem-based fishery management. *Ecological Economics* **64**, 586-596.
- Schmitt, K.M., Kramer, D.B. (2009) Road development and market access on Nicaragua's Atlantic coast: implications for household fishing and farming practices. *Environmental Conservation* **36**, 289-300.
- Sievanen, L., Crawford, B., Pollnac, R., Lowe, C. (2005) Weeding through assumptions of livelihood approaches in ICM: Seaweed farming in the Philippines and Indonesia. *Ocean & Coastal Management* **48**, 297-313.
- Smith, M.D., Lynham, J., Sanchirico, J.N., Wilson, J.A. (2010) Political economy of marine reserves: Understanding the role of opportunity costs. *Proceedings of the National Academy of Sciences of the United States of America* **107**, 18300-18305.
- Smith, M.D., Zhang, J., Coleman, F.C. (2005) Effectiveness of marine reserves for large-scale fisheries management *Canadian Journal of Fisheries and Aquatic Sciences* **63**, 153-164.
- Stallings, C.D. (2009) Fishery-independent data reveal negative effect of human population density on Caribbean predatory fish communities. *Plos One* **4**, 9.

- Steneck, R.S., Hughes, T.P., Cinner, J.E., *et al.* (in press) High economic value creates a gilded trap for the Maine lobster fisher. *Conservation Biology*.
- Walking Fish: A community supported fishery (www.walking-fish.org) Last accessed 7 March 2011.
- Watson, M., Ormond, R.F.G. (1994) Effect of an artisanal fishery on the fish and urchin populations of a Kenyan coral reef. *Marine Ecology Progress Series* **109**, 115-129.
- Wilkinson, C. (2008) *Status of coral reefs of the world: 2008*, Vol., Global Coral Reef Monitoring Network and Reef and Rainforest Research Centre, Townsville, Australia.
- Williamson, D., Russ, G., Ayling, A. (2004) No-take marine reserves increase abundance and biomass of reef fish on inshore fringing reefs of the Great Barrier Reef. *Environmental Conservation* **31**, 149-159.
- Wilson, S.K., Adjeroud, M., Bellwood, D.R., *et al.* (2010) Crucial knowledge gaps in current understanding of climate change impacts on coral reef fishes. *Journal of Experimental Biology* **213**, 894-900.
- Wing, S.R., Wing, E.S. (2001) Prehistoric fisheries in the Caribbean. *Coral Reefs* **20**, 1-8.
- Zann, L.P. (1999) A new (old) approach to inshore resources management in Samoa. *Ocean & Coastal Management* **42**, 569-590.

CHAPTER 2:

Reducing bycatch in coral reef trap fisheries: escape gaps as a step towards sustainability

Vol. 415: 201–209, 2010
doi: 10.3354/meps08762

MARINE ECOLOGY PROGRESS SERIES
Mar Ecol Prog Ser

Published September 29

Reducing bycatch in coral reef trap fisheries: escape gaps as a step towards sustainability

Ayana Elizabeth Johnson*

Center for Marine Biodiversity and Conservation, Scripps Institution of Oceanography, University of California,
San Diego, 9500 Gilman Drive, La Jolla, California 92083-0202, USA

ABSTRACT: Widespread use of minimally selective fish traps has contributed to the overfishing of Caribbean coral reefs. Traps typically target high-value fish such as groupers (Serranidae and Epinephelidae) and snappers (Lutjanidae), but they also have high bycatch of ecologically important herbivores (parrotfish (Scaridae) and surgeonfish (Acanthuridae)) and non-target species. One strategy for reducing this bycatch is to retrofit traps with rectangular escape gaps that allow juveniles and narrow-bodied species to escape; yet the effectiveness of these gaps has not been thoroughly tested. On the shallow reefs of Curaçao, Netherlands Antilles, I compared the catch of traditional Antillean chevron traps (the control) to the catch of traps with short escape gaps (20 × 2.5 cm), traps with tall escape gaps (40 × 2.5 cm), and traps with a panel of large aperture mesh. With data from 190 24-h trap sets, the mean number of fish caught was 11.84 in control traps, 4.88 in short gap traps, 4.43 in tall gap traps, and 0.34 in large mesh traps. Compared to controls, traps with short or tall gaps caught significantly fewer bycatch fish (–74 and –80 % respectively), key herbivores (–58 and –50 % respectively), and butterflyfish (Chaetodontidae; –90 and –98 % respectively). The mean length of captured fish was significantly greater in gap traps because juveniles were able to escape via the gaps. Escape gaps reduce neither the catch of high-value fish, nor the total market value of the catch. Therefore, using escape gaps could make trap fishing more sustainable without reducing fishermen's revenues.

KEY WORDS: Fish traps · Bycatch · Escape gaps · Parrotfish · Caribbean · Coral reef fisheries · Gear-based fisheries management · Artisanal fisheries

Resale or republication not permitted without written consent of the publisher

INTRODUCTION

Catch of coral reef fish even at an artisanal scale can lead to severe overfishing (Jackson 1997, Hawkins & Roberts 2004). Management efforts to prevent this are complicated by the multi-species and multi-gear nature of reef fisheries. Gear-based fisheries management, an approach that exploits differences between gear types in order to indirectly control catch composition (McClanahan & Mangi 2004, McClanahan & Cinner 2008), can increase fishery selectivity, and thereby sustainability. Within this context, the present study focuses on fish traps, which are both responsible for the majority of reef fish captured in the Caribbean and around the world (Gobert 1998, Mahon & Hunte 2001), and known for high levels of bycatch (Stewart 2007).

Bycatch, defined as discarded plus incidental fish catch (Alverson et al. 1994), hinders fishery sustainability by accelerating the depletion of fish stocks. Although discard rates are typically low in artisanal fisheries (Hawkins et al. 2007), incidental catch of juveniles and non-target species is still a great concern. Fish traps usually retain most fish that enter, resulting in high catch biodiversity (Munro 1983) and high bycatch of juvenile fish and non-target species (often >50 % of the catch; Ferry & Kohler 1987), leading to overexploitation of reef fish populations even with relatively low effort (Hardt 2008).

Research on trap catch composition (i.e. quantity, size distribution, and species diversity) and the factors affecting it has been conducted for several decades. Beginning with Munro's comprehensive work in

*Email: ayana-johnson@ucsd.edu

Jamaica in the 1970s, researchers have examined the influences of soak time, trap shape, bait, habitat type, conspecific attraction, lunar phase, and local level of exploitation (e.g. Munro et al. 1971, Munro 1974, Ferry & Kohler 1987, Dalzell & Aini 1992, Wolff et al. 1999, Robichaud et al. 2000, Garrison et al. 2004). However, research on the management of trap fisheries has focused almost exclusively on the use of larger mesh sizes to reduce the catch of juveniles (e.g. Bohnsack et al. 1989, Robichaud & Hunte 1997, Sary et al. 1997, Stewart 2007). One drawback of this approach is that, given the diversity of fish caught with traps, it is impossible to select one mesh size that optimizes the yield of all exploited species (Mahon & Hunte 2001). An alternative modification to fish traps, the inclusion of escape gaps that allow juveniles and narrow-bodied species to exit, is a promising method of bycatch reduction that deserves further investigation.

Munro et al. (2003) tested escape gaps (largest gap size 9.0×3.3 cm) in double-arrowhead-shaped traps (an experimental trap design not used by fishermen), and showed that gaps reduce both catch quantity and catch mass relative to controls. Inspired by Curaçao's proposed regulation to require escape gaps in all traps, I employed typical Antillean traps to build upon Munro's work. Here I provide family composition, quantity, length, mass and value data for the catch of 4 types of fish traps, then consider the ecological and economic implications of requiring escape gaps use, and directly compare escape gap and mesh size management options.

MATERIALS AND METHODS

Study sites. From May through August 2008, I experimentally fished with 4 types of fish traps at 3 sites on the northwest coast of Curaçao, Netherlands Antilles (all near $12^{\circ} 19' N$, $69^{\circ} 09' W$): Lagún, Santa Marta, and Westpunt. All 3 locations are fringing reefs where a light level of fishing (several small boats a day) is occurring. The benthic habitats of the sites differ somewhat in terms of rugosity, reef slope, and species composition, thereby increasing the generality of the experimental results.

Fish biomass on Curaçao's shallow reefs is considered high relative to many other locations in the Caribbean (Sandin et al. 2008), but low in comparison to protected areas on the Mesoamerican Barrier Reef and Cuba (Newman et al. 2006). Traps account for almost 60% of Curaçao's reef fish landings by weight (Dilrosun 2002), and the trap fishery is currently unregulated.

Trap design. Control traps were tested against traps retrofitted with one of 3 experimental treatments:

1 panel of large-aperture mesh, 2 short (20×2.5 cm) escape gaps, or 2 tall (40×2.5 cm) escape gaps (Fig. 1). All traps were handmade by a local fisherman in the traditional Antillean chevron shape. Traps differed slightly in exact dimensions, but all trap volumes were ~ 0.50 m³. Tree-branches formed the frames, and galvanized '1-inch' wire mesh (hexagonal mesh, aperture 2.7 high by 3.5 cm wide) was attached to all sides of the traps with bailing wire. The entrances were down-curving, tapering cylinders with a horse neck shape. One side panel of each trap was affixed to the frame using cable ties so that it could be used as a door. Escape gaps were constructed from 0.8 cm diameter steel reinforcement bars ('rebar') that were bent, welded, and secured to the traps with cable ties.

I selected the aperture of the large mesh (hexagonal mesh, aperture 5×8 cm) based on research that recommended a minimum aperture of 5.1 cm in order to optimize catch for consumption (Mahon & Hunte 2001). Large mesh was only used for one panel of the large mesh traps so as to maintain the visual image (a concern in trap studies such as Robichaud et al. 1999) and the structural integrity of the traps (a concern of fishermen). Visual image refers to how visible the traps are, which is relevant because fish can be attracted to structure.

Experimental design. The experiment employed a randomized block design. At each site, I set 8 traps (2 of each type) in reef habitat at 12 to 15 m depth at

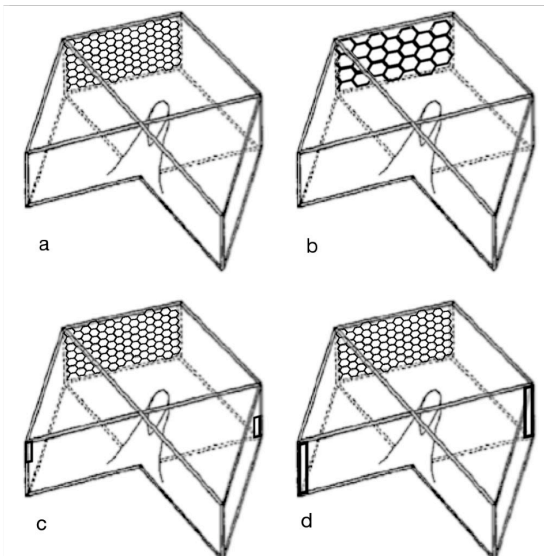


Fig. 1. The 4 types of fish traps used in this experiment: (a) control (traditional Antillean arrowhead trap), and traps with (b) 1 large mesh panel, (c) 2 short (20×2.5 cm) escape gaps, and (d) 2 tall (40×2.5 cm) escape gaps. (Adapted from image in Munro et al. 1971)

marked locations 25 m apart. Each week, I closed the doors of the traps using cable ties and left the traps submerged for 24 h following the common practice of Curaçaoan fishermen. I refer to this 24-h soak time as a trap set. Traps were not baited, as previous studies have shown that bait does not influence trap effectiveness (e.g. Munro et al. 1971). Using SCUBA, I checked trap contents and recorded the species, fork length, and condition of each fish. I then cut the cable ties securing the doors of the traps to release the trapped fish, and left the doors in the open position until the start of the next week of the experiment. To mitigate the potential problem of differential catch between trap locations within a site, all traps were randomly reshuffled amongst the marked locations every week.

Length to weight conversions. To convert fish fork length (L) in centimeters into weight (W) in grams, I employed the standard allometric relationship: $W = aL^b$. Values for the constants 'a' and 'b' were obtained for each species from FishBase (Froese & Pauly 2009), using congeners if necessary. Where multiple 'a' and 'b' values were available for a species, I selected values from Caribbean studies with the largest sample sizes. As the present study focuses broadly on trap fishing effects, I pooled data to the family level for analysis.

Fish categorizations and market value. I assigned families of captured fish to one of 4 market value categories: (1) high-value fish, (2) key herbivores, (3) sochi (the Papiamentu term for a mixed-species group of reef fish that are sold collectively at one price), or (4) bycatch (see Table 1 for categorizations). I obtained fish prices by interviewing 8 fish vendors, and asking them to estimate the prices at which they had pur-

chased various fish from fishermen in the past several months. Their responses were consistent and are presented in Table 1. Groupers (Epinephelidae) refers only to *Cephalopholis cruentata* (graysby) and *C. fulva* (coney) as no other grouper species were captured. Parrotfish (Scaridae) and surgeonfish (Acanthuridae) are often sold as sochi, but for this analysis are placed in a separate 'key herbivores' category. Fish for which all vendors reported zero market value were categorized as bycatch. Fish in the bycatch category are discarded at sea, given away as food, or occasionally used as bait. Moray eels (Muraenidae) were included only in the family level analyses because their weight and length mask, without changing the direction of, treatment effects. Also, morays are sold very infrequently, and therefore have little effect on catch value. For calculation of catch values, fish that were dead or in poor condition, and therefore not saleable, were assigned a market value of zero. Fish considered to be in poor condition were those that had major visible damage (e.g. severe scratches or bite marks) or were no longer actively swimming.

Data analyses. I present data for number of fish caught and catch value at the trap level, data for length at the individual fish level, and for mass at both the fish and trap levels. I compared these variables across the 4 trap types and 3 sites using 2-way ANOVAs, treating both trap type and study site as fixed effects. Note that including trap set date as an additional fixed factor in a 3-way ANOVA with each of the main catch metrics (quantity, length, mass, and value) as response variables revealed no significant effects of date on catch, and, thus, set date is subsequently ignored. With 1-way ANOVAs and Bonferroni corrections for multi-

Table 1. Mean market value, included families, primary importance, and potential effects of removal from the ecosystem, for the 4 fish market value categories. Prices are given in US dollars. Importance is within the context of the present study

Category	Mean market value (kg ⁻¹)	Families included	Primary importance	Potential effects of removal
High-value fish	\$5.85	Lutjanidae (snappers) Epinephelidae (groupers)	Most valuable catch	Reduced income for fishermen
Key herbivores	\$2.94	Acanthuridae (surgeonfish) Scaridae (parrotfish)	Eat algae	Increased algal dominance
Sochi	\$3.15	Balistidae (triggerfish) Haemulidae (grunts) Holocentridae (squirrelfish) Labridae (wrasses) Mullidae (goatfish) Pomacanthidae (angelfish)	Various	Reduced diversity and associated interactions
Bycatch	\$0.00	Bothidae (flounders) Chaetodontidae (butterflyfish) Monacanthidae (filefish) Ostraciidae (trunkfish) Pomacentridae (damselfish)	Biodiversity	Reduced tourist attraction

ple comparisons, I compared the catches of fish <10 cm, of each of the commonly caught families, and of each of the fish market value categories. For significant ANOVA models, I used Tukey-Kramer pairwise comparisons to identify differences in catch between the control and each experimental trap type. Where >1 experimental trap type differed from the control, the minimum Tukey-Kramer q -value is given. All reported errors are standard errors. To account for potential effects of any undetected spatial and temporal autocorrelation, I present clustered (i.e. robust) standard errors. This approach is analogous to including a random effects term in a standard ANOVA.

RESULTS

Over the course of the experiment, 190 traps were set and 1028 fish were captured. Although catch varied across fished sites (see Table 2 for details of effect of location), it did not affect the relative difference of treatment effects and is thus not discussed further.

Diversity of catch

I captured 44 species from 19 families. Twenty-seven species from 6 families made up 84 % of the catch, with clear differences in catch composition between trap types (Fig. 2). When compared directly with each other, there were no significant differences between the catches of short and tall gap traps at the family level. Compared with controls, traps with either short

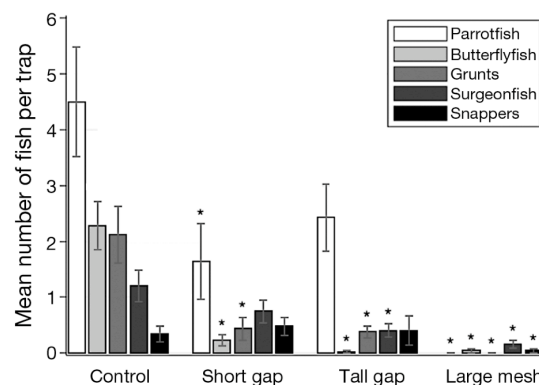


Fig. 2. Mean ($\pm$ SE) catch composition of trap sets for families representing 5% or more of the total catch of control traps. Significant differences from controls are indicated; * $p < 0.05$

or tall gaps caught significantly fewer grunts (*Haemulidae*, $F_{3,186} = 11.7$, $p < 0.001$; Tukey-Kramer minimum $q = 5.48$, $p < 0.001$) and butterflyfish (*Chaetodontidae*, $F_{3,186} = 20.52$, $p < 0.001$; $q = 8.88$, $p < 0.001$), and tall gap traps also reduced the catch of surgeonfish ($F_{3,186} = 5.80$, $p < 0.001$; $q = 4.08$, $p < 0.025$; Fig. 2). Of all the captured families, butterflyfish displayed the most dramatic catch declines: –90 % with short gaps and –98 % with tall gaps compared to a control mean of 2.28 butterflyfish per trap set. Parrotfish comprised the greatest proportion of the catch in all trap types (except for large mesh traps, which caught no parrotfish), although short gap traps did catch 63 % fewer parrotfish than the control mean of 4.5 per trap set ($F_{3,186} = 8.11$, $p < 0.001$; $q = 4.31$, $p < 0.01$). *Scarus taeniopterus* (princess parrotfish) and *Sparisoma aurofrenatum* (redband parrotfish) represented the majority of captured scarids. Moray eels were present in 22 % of the trap sets, and the number of morays captured is significantly lower only for the large mesh relative to the control ($F_{3,186} = 3.25$, $p = 0.023$; $q = 4.09$, $p < 0.025$; Fig. 2). Importantly, the catch of snappers (*Lutjanidae*, a prime target of trap fishermen) was not significantly different across trap types.

Quantity of catch

Quantity of catch per trap set was significantly lower in all modified trap types (short gap, tall gap, and large mesh) relative to the control mean of 11.84 fish (Table 2, Fig. 3a). Large mesh traps caught only 17 fish over the entire experiment, and over two-thirds of trap sets in this treatment caught zero fish. On average, large mesh traps caught 0.34 fish per trap set, a difference of –97.1 % relative to control traps. Because of

Table 2. Results of ANOVAs testing for significant differences between trap types and research sites. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.0001$

	<i>F</i>	df
Mean number		
Trap type	26.41***	3
Site	12.86***	2
Trap type $\times$ site	3.12**	6
Mean length (cm)		
Trap type	15.78***	3
Site	1.63	2
Trap type $\times$ site	2.92**	6
Mean mass (kg)		
Trap type	13.76***	3
Site	8.61**	2
Trap type $\times$ site	2.32*	6
Mean value (USD)		
Trap type	6.91**	3
Site	5.93**	2
Trap type $\times$ site	1.77	6

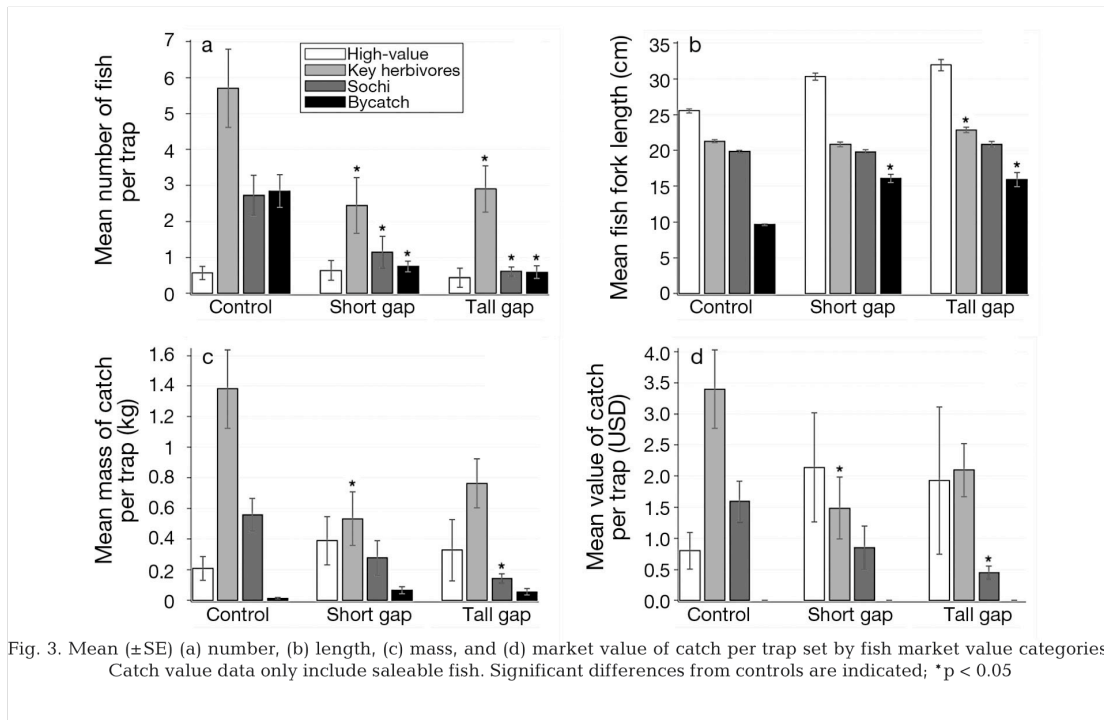


Fig. 3. Mean ($\pm$ SE) (a) number, (b) length, (c) mass, and (d) market value of catch per trap set by fish market value categories. Catch value data only include saleable fish. Significant differences from controls are indicated; * $p < 0.05$

this extremely low catch, results for this trap type are excluded from Fig. 3. Short and tall escape gap traps respectively caught means of 4.88 and 4.43 fish per trap set, differences of -59 and -63% relative to control traps. Key herbivores were the largest component of catch in all trap types, representing 48% of the fish caught in control traps, 47% in large mesh, 49% in short gap, and 64% in tall gap traps; although both gap heights did significantly reduce the quantity of key herbivores captured ($F_{3,186} = 9.82$, $p < 0.0001$; $q = 3.77$, $p < 0.025$; Fig. 3a). Both gap heights also significantly reduced the quantity of sochi ($F_{3,186} = 9.85$, $p < 0.0001$; $q = 4.36$, $p < 0.01$) and bycatch ($F_{3,186} = 22.83$, $p < 0.0001$; $q = 8.18$, $p < 0.001$) captured (Fig. 3a). The mean catch quantities for short and tall gaps respectively were 2.40 and 2.83 key herbivores per trap set (differences of -58 and -50% relative to controls), 1.13 and 0.60 sochi fish per trap set (-59 and -78% relative to controls), and 0.73 and 0.57 bycatch fish per trap set (-74 and -80% relative to controls). Notably, there were no significant differences between trap types in the quantity of high-value fish captured.

Length of catch

The mean length of fish retained in traps with escape gaps was significantly greater than that of fish in control traps (Table 3, Fig. 3b). Compared to controls,

short and tall gap traps both caught significantly fewer fish <10 cm in fork length ($F_{3,186} = 20.36$, $p < 0.0001$; $q = 6.82$, $p < 0.025$). The mean lengths of fish caught in short and tall gap traps were 21.11 and 22.59 cm respectively, differences of +13 and +19% relative to fish in control traps. The mean length of fish in large mesh traps was not significantly different from the control mean. When examined by value categories, the mean length of bycatch fish was greater in both the short and tall gap traps ($F_{3,200} = 12.80$, $p < 0.0001$; $q = 6.07$, $p < 0.001$), the mean length of key herbivores was greater in tall gap traps ($F_{3,523} = 4.33$, $p = 0.005$; $q = 3.94$, $p < 0.025$), and the mean length of sochi and high-value fish remained unchanged across trap types (Fig. 3b). Mean length of bycatch fish, which are often narrow-bodied and therefore likely to escape via the gaps, was 16.07 and 15.94 cm in short gap and tall gap traps respectively, differences of approximately +65% relative to fish caught in control traps.

Biomass of catch

The mean mass of an individual captured fish was 228 ± 10.4 g for control traps, 276 ± 18.8 g for short gaps, 293 ± 23.4 g (significantly longer than controls) for tall gaps, and 401 ± 103.6 g for large mesh traps ($F_{3,891} = 4.81$, $p < 0.01$; $q = 3.98$, $p < 0.025$). The mean total mass per trap set was significantly lower in short gap and

Table 3. Data for number, mass, and value of fish captured per trap set, and data for fork length per fish. Means, SE, sample sizes (n), and percent difference from control are presented for each trap type. Overall percent differences and differences for each site (Lagún = L, Santa Marta = S, and Westpunt = W) are presented. Means significantly different from control are indicated; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.0001$

	Mean ± SE	n	Overall (%)	Difference (%) Per site (L, S, W)
Mean number				
Control		50		
Short gap	11.84 ± 1.92	48	−58.9	(−37.7, −47.2, −91.6)
Tall gap	4.88 ± 1.91***	42	−62.6	(−44.1, −61.7, −78.4)
Large mesh	4.43 ± 1.81***	50	−97.1	(−95.8, −97.9, −97.6)
	0.34 ± 1.92***			
Mean length (cm)				
Control		591		
Short gap	18.37 ± 0.45	234	+14.9	(+12.5, +20.0, +0.4)
Tall gap	21.11 ± 0.97**	186	+23.0	(+19.9, +21.8, +31.1)
Large mesh	22.59 ± 0.88***	17	+14.5	(+5.2, +49.7, +0.7)
	21.03 ± 3.06			
Mean mass (kg)				
Control		50		
Short gap	2.17 ± 0.36	48	−41.5	(−10.1, −24.0, −90.8)
Tall gap	1.27 ± 0.45*	42	−38.2	(−26.7, −39.6, −52.5)
Large mesh	1.34 ± 0.37	50	−94.5	(−93.6, −92.2, −97.2)
	0.12 ± 0.36***			
Mean value (USD)				
Control	5.77 ± 1.00	50		
Short gap	4.47 ± 1.57	48	−22.5	(+34.3, −9.8, −92.2)
Tall gap	4.59 ± 1.44	42	−20.5	(−25.0, −12.5, −28.6)
Large mesh	0.52 ± 1.03***	50	−91.0	(−92.2, −83.4, −96.7)

large mesh traps relative to controls (Table 3, Fig. 3c). Key herbivores dominated the mass of trap catches, representing 64 % of the mass in controls, 42 % in short gap, and 59 % in tall gap traps. There were no significant differences between the masses of high-value fish or bycatch fish captured by gap and control traps, but relative to controls, the mass of key herbivores was lower in short gap traps ($F_{3,186} = 10.56$, $p < 0.0001$; $q = 4.89$, $p < 0.005$), and the mass of sochi was lower in tall gap traps ($F_{3,186} = 7.75$, $p < 0.001$; $q = 4.91$, $p < 0.005$; Fig. 3c). However, when short and tall gaps are compared directly with each other, there were no significant differences in the mass of key herbivores ($q = 1.27$, $p > 0.1$) or sochi ($q = 1.57$, $p > 0.1$) caught.

Market value of catch

There were no significant differences in overall catch value between gap and control traps (Table 3), but there were differences at the level of market value categories (Fig. 3d). The value of key herbivores in traps with short gaps was \$1.49 US, a difference of –56 % relative to control traps ($F_{3,186} = 9.29$, $p < 0.0001$; $q = 4.29$, $p < 0.01$), and the value of sochi in traps with tall gaps was \$0.45 US, a difference of –71 % relative to

control traps ($F_{3,186} = 6.18$, $p < 0.001$; $q = 4.29$, $p < 0.01$). However, when short and tall gap traps were compared directly to each other, there were no significant differences in the values of key herbivores ($q = 1.29$, $p > 0.1$) or sochi ($q = 1.49$, $p > 0.1$) caught. Most notably, the value of the high-value fish targeted by fishermen was not significantly different between gap and control traps. Of captured fish, 4 % (and 7 % of captured parrotfish) were dead or in poor condition and therefore not included in the value calculations. The mean catch value of large mesh traps was significantly lower than that of controls at only \$0.52 US per trap set.

DISCUSSION

Escape gaps significantly reduce the bycatch of traditional Antillean fish traps while maintaining overall catch value (Fig. 3), and as such represent an important opportunity for increasing the sustainability of trap fisheries. This is in contrast with large mesh, which greatly reduces catch value while reducing bycatch. Despite the fact that gap traps resulted in a ~60 % decrease in number of fish captured, mass of catch only dropped by ~40 % because the length of the catch in gap traps was ~20 % greater (Table 3). The

catch of surgeonfish, butterflyfish, and fish <10 cm was significantly lower in both the short and tall gap traps, implying that narrow-bodied and/or small fish that enter traps can locate the gaps and escape (Fig. 2). Parrotfish dominated catches in the control and gap traps, both numerically and in terms of biomass. Compared to parrotfish, high-value groupers and snappers represented a much smaller proportion of the catch quantity in control and gap traps, but were still an important component of catch value, and the per trap set value of high-value fish did not differ between trap types.

The difference in effectiveness of the 2 gap sizes appears to be nominal as catch composition in the short and tall gap traps was very similar. The significant differences were that, relative to control traps, only tall gaps increased the mean length of key herbivores, only short gaps reduced the mean mass and value of key herbivores, and only tall gaps reduced the mean mass and value of sochi. However, when short and tall gap traps are compared directly to each other, these mass and value differences are not significant. Thus, specific gap height appears to be much less important than whether or not a gap is used. The fisheries department of Curaçao has proposed the required use of short (20 × 2.5 cm) escape gaps in all fish traps. The choice of short versus tall gaps there could have minor consequences for trap catch composition, but should not affect catch values.

Although this experiment was conducted on a single island, in a single season, at a single depth, and is therefore only a snapshot of the potential effectiveness of escape gaps, the general finding that some of the smaller, less marketable fish escape would likely apply to most trap fisheries. The specifics of how gaps would change trap catch composition and value elsewhere depend on location-specific fish population demographics and definitions of bycatch. Short of repeating this experiment in other areas where trap fishing is occurring, it could be informative to re-calculate the potential effects of gaps on catch value using location-specific fish market values.

The minimal cost of retrofitting Antillean traps (<\$1 US per trap) and the undiminished catch value are especially important attributes of escape gaps given the already tenuous profitability of some trap fisheries (Mangi et al. 2007). Escape gaps can be constructed from a diversity of materials, and gap dimensions can be tailored to retain specific target species. This is in contrast with the traditional approach of regulating trap fisheries by mesh size, which can increase selectivity but simultaneously render traps unprofitable. Mesh size retrofits are costly and a hexagonal mesh aperture tall enough to let out a butterflyfish would also be wide enough to let out a market-sized snapper. Other studies have observed similarly large (80 to

95 %) catch reductions resulting from increased mesh size, with target species representing a great portion of those declines (e.g. Bohnsack et al. 1989, Robichaud et al. 1999, Mahon & Hunte 2001). This reduction may be due to lack of a 'live bait effect': though small fish in gap traps may eventually escape, the time they spend in the trap can attract larger fish. The apertures in large mesh traps can be too large to retain small fish long enough to produce this effect. However, mesh size restrictions might be a viable regulatory approach where fish populations are less depleted. The fact that 5 cm mesh traps catch so few fish can be considered a measure of the degradation of Caribbean reef fish populations (Knowlton & Jackson 2008).

Trap use in reef habitats is globally widespread, making it worthwhile to consider the potential ramifications of a broad adoption of escape gaps. As traps with tall gaps catch a mean 7.4 fewer fish (including a mean 2.9 fewer key herbivores) than control traps, it follows that retrofitting the ~100 actively used traps on Curaçao could reduce bycatch there by tens of thousands of fish annually. Considering there are more than 20 000 active fish traps in Puerto Rico and the United States Virgin Islands alone (Sheridan et al. 2003), use of escape gaps throughout the Caribbean has the potential to reduce bycatch and herbivore catch by millions of fish annually.

In the last half-century, Caribbean trap catch composition has shifted from carnivore (snapper and grouper) to herbivore (parrotfish and surgeonfish) dominance (Garrison et al. 1998), yet another example of 'fishing down food webs' (Pauly et al. 1998). Parrotfish and surgeonfish, formerly considered undesirable (Zaneveld 1961), are now commonly being marketed in Curaçao and are increasingly available in supermarkets and restaurants in the United States (author's pers. obs.). This is of particular concern because parrotfish have become the principal grazers on Caribbean reefs since the regional die-off of the sea urchin *Diadema antillarum* in 1983 (Lessios et al. 1984), and because large parrotfish, which are retained in traps, consume disproportionately more algae per fish than their smaller congeners (Bruggemann et al. 1996).

Gear-based management has been touted as a way to account for this increased importance of herbivores in supporting the resilience of a coral-dominated benthos, and as a means to adaptively manage reef fisheries in the context of climate change (McClanahan et al. 2008, Cinner et al. 2009). Of all the types of fishing gear commonly used on reefs, traps catch the greatest proportion of herbivores (McClanahan et al. 2008); it is therefore important to manage their use, and escape gaps could help to reduce herbivore mortality.

Apart from high herbivore catch, fish traps have additional detrimental effects on reefs that cannot be

mitigated by escape gaps. First, they can cause physical damage to benthic habitats when they are set, hauled, lost or abandoned (Chiappone et al. 2002, Sheridan et al. 2003, Mangi & Roberts 2006). Also, traps catch moray eels, which likely serve an important but often underappreciated predatory role in coral reef ecosystems, especially in areas where large groupers and snappers have been overfished (Gilbert et al. 2005). Further, escape gaps do not reduce catch of wide-bodied bycatch fish (such as trunkfish (Ostraciidae), and scorpionfish (Scorpaenidae)), nor do they allow escape of the large fish that are disproportionately important to reproductive potential (Birkeland & Dayton 2005). Last, escape gaps do not eliminate the issue of fish being injured and dying in the traps, and thus becoming unmarketable. While escape gaps are a very effective bycatch reduction tool, it is unlikely that any amount of tinkering with trap design will sufficiently ameliorate these concerns. Additionally, gear modifications such as escape gaps can be less effective in practice because fishermen may use the gear differently than researchers, and without enforcement compliance can be low (Cox et al. 2007). Hence, from an ecosystem perspective, additional restrictions on trap fishing are warranted.

Nevertheless, escape gaps could create long-term benefits that are at least 3-fold. First, reduced catch of key herbivores could promote healthier reefs via increased algal grazing (Burkepile & Hay 2008). Second, reduced catch of juveniles could result in a greater number of reproductively mature fish, thereby increasing population productivity. Third, reduced catch of bycatch fish could increase biodiversity, and thereby tourist interest, since many recreational divers consider species diversity a key attraction of coral reef dives (Parsons & Thur 2008). Escape gaps have great potential to benefit both fishermen and conservation, and requiring escape gaps in all reef environments where traps are used would represent an important step towards sustainable management.

Acknowledgements. J. B. C. Jackson, S. A. Sandin, J. Smith, L. Levin, P. Hastings, and T. Groves provided guidance from inception through submission. The comments of 4 anonymous reviewers were helpful in improving the manuscript. I am very grateful to my colleagues in Curaçao: F. Dilrosun, H. Zimmerman, D. Kolunousky, M. Kolunousky, M. Vermeij, and G. van Buurt. C. Sprenger contributed invaluable statistical prowess. C. Dodge, K. Marhaver, K. Nichols, M. Goldstein, H. Czerski, C. Angioletti, and B. Neal provided diving assistance. This material is based upon work supported by the National Science Foundation under Grant No. 0333444 and a Graduate Research Fellowship. Additional funding was provided by Scripps Institution of Oceanography, Russ and Eloise Duff, Curaçao, Dienst Landbouw, Veeteelt & Visserij (LVV), PADI Foundation, Easy Divers at Habitat Curaçao, Sunset Divers, and Foundation Reef Care Curaçao.

LITERATURE CITED

- Alverson DL, Freeberg MH, Murawski SA, Pope JG (1994) A global assessment of fisheries bycatch and discards. FAO Fisheries Technical Paper. No. 339. FAO, Rome
- ▶ Birkeland C, Dayton PK (2005) The importance in fishery management of leaving the big ones. *Trends Ecol Evol* 20: 356–358
- Bohnsack JA, Sutherland DL, Harper DE, McClellan DB, Hulsbeck MW, Holt CM (1989) The effects of fish trap mesh size on reef fish catch off southeastern Florida. *Mar Fish Rev* 51:36–46
- ▶ Bruggemann JH, van Kessel AM, van Rooij JM, Breeman AM (1996) Bioerosion and sediment ingestion by the Caribbean parrotfish *Scarus vetula* and *Sparisoma viride*: implications of fish size, feeding mode and habitat use. *Mar Ecol Prog Ser* 134:59–71
- ▶ Burkepile DE, Hay ME (2008) Herbivore species richness and feeding complementarity affect community structure and function on a coral reef. *Proc Natl Acad Sci USA* 105: 16201–16206
- ▶ Chiappone M, White A, Swanson DW, Miller SL (2002) Occurrence and biological impacts of fishing gear and other marine debris in the Florida Keys. *Mar Pollut Bull* 44: 597–604
- Cinner JE, McClanahan TR, Graham NAJ, Pratchett MS, Wilson SK, Raina J (2009) Gear-based fisheries management as a potential adaptive response to climate change and coral mortality. *J Appl Ecol* 46:724–732
- ▶ Cox TM, Lewison RL, Zydels R, Crowder LB, Safina C, Read AJ (2007) Comparing effectiveness of experimental and implemented bycatch reduction measures: the ideal and the real. *Conserv Biol* 21:1155–1164
- Dalzell P, Aini JW (1992) The performance of Antillean wire mesh fish traps set on coral reefs in northern Papua, New Guinea. *Asian Fish Sci* 5:89–102
- Dilrosun F (2002) Progress report on Curaçao fishery monitoring program. FAO Fisheries R683 Suppl, p 9–20. Available at: <http://www.fao.org/docrep/005/y4260e/y4260e05.htm>
- ▶ Ferry RE, Kohler CC (1987) Effects of trap fishing on fish populations inhabiting a fringing coral reef. *N Am J Fish Manage* 7:580–588
- Froese R, Pauly D (2009) FishBase, available at www.fishbase.org (accessed August 22, 2009)
- Garrison VH, Rogers CS, Beets J (1998) Of reef fishes, overfishing and in situ observations of fish traps in St. John, US Virgin Islands. *Rev Biol Trop* 46:41–59
- ▶ Garrison VH, Rogers CS, Beets J, Friedlander AM (2004) The habitats exploited and the species trapped in a Caribbean island trap fishery. *Environ Biol Fishes* 71:247–260
- Gilbert M, Rasmussen JB, Kramer DL (2005) Estimating the density and biomass of moray eels (Muraenidae) using a modified visual census method for hole-dwelling reef fauna. *Environ Biol Fishes* 73:415–426
- ▶ Gobert B (1998) Density-dependent size selectivity in Antillean fish traps. *Fish Res* 38:159–167
- Hardt MJ (2008) Lessons from the past: the collapse of Jamaican coral reefs. *Fish Fish* 10:1–16
- ▶ Hawkins JP, Roberts CM (2004) Effects of artisanal fishing on Caribbean coral reefs. *Conserv Biol* 18:215–226
- ▶ Hawkins J, Roberts C, Gell F, Dytham C (2007) Effects of trap fishing on reef fish communities. *Aquat Conserv* 17: 111–132
- ▶ Jackson JBC (1997) Reefs since Columbus. *Coral Reefs* 16: S23–S32
- Knowlton N, Jackson JBC (2008) Shifting baselines, local impacts, and global change on coral reefs. *PLoS Biol* 6:215–220

- ▶ Lessios HA, Robertson DR, Cubitt JD (1984) Spread of *Diadema* mass mortality through the Caribbean. *Science* 226:335–337
- Mahon R, Hunte W (2001) Trap mesh selectivity and the management of reef fishes. *Fish Fish* 2:356–375
- ▶ Mangi SC, Roberts CM (2006) Quantifying the environmental impacts of artisanal fishing gear on Kenya's coral reef ecosystems. *Mar Pollut Bull* 52:1646–1660
- ▶ Mangi SC, Roberts CM, Rodwell LD (2007) Financial comparisons of fishing gear used in Kenya's coral reef lagoons. *Ambio* 36:671–676
- ▶ McClanahan TR, Cinner JE (2008) A framework for adaptive gear and ecosystem-based management in the artisanal coral reef fishery of Papua New Guinea. *Aquat Conserv* 18:493–507
- ▶ McClanahan TR, Mangi SC (2004) Gear-based management of a tropical artisanal fishery based on species selectivity and capture size. *Fish Manag Ecol* 11:51–60
- McClanahan TR, Ruiz Sebastian C, Cinner J, Maina J, Wilson S, Graham NAJ (2008) Managing fishing gear to encourage ecosystem-based management of coral reefs fisheries. *Proc 11th Int Coral Reef Symp*, Ft. Lauderdale, FL
- Munro JL (1974) Mode of operation of Antillean fish traps and relationships between ingress, escapement, catch and soak. *J Cons Int Explor Mer* 35:337–350
- Munro JL (ed) (1983) The composition and magnitude of trap catches in Jamaican waters. In: *Caribbean Coral Reef Fishery Resources*. ICLARM, Manila, p 33–49
- Munro JL, Reeson PH, Gaut VC (1971) Dynamic factors affecting the performance of the Antillean fish trap. *Annu Proc Gulf Caribb Fish Inst* 23:184–194
- Munro JL, Sary Z, Gell FR (2003) Escape gaps: an option for the management of Caribbean trap fisheries. *Annu Proc Gulf Caribb Fish Inst* 54:28–40
- ▶ Newman M, Paredes G, Sala E, Jackson J (2006) Structure of Caribbean coral reef communities across a large gradient of fish biomass. *Ecol Lett* 9:1216–1227
- ▶ Parsons GR, Thur SM (2008) Valuing changes in the quality of coral reef ecosystems: a stated preference study of SCUBA diving in the Bonaire National Marine Park. *Environ Resour Econ* 40:593–608
- ▶ Pauly D, Christensen V, Dalsgaard J, Froese R, Torres F Jr (1998) Fishing down marine food webs. *Science* 279: 860–863
- Robichaud D, Hunte W (1997) What factors explain reduced fishing power with increased mesh size of Antillean fish traps? *Proc Gulf Caribb Fish Inst* 49:273–279
- ▶ Robichaud D, Hunte W, Oxenford HA (1999) Effects of increased mesh size on catch and fishing power of coral reef fish traps. *Fish Res* 39:275–294
- Robichaud D, Hunte W, Chapman MR (2000) Factors affecting the catchability of reef fishes in Antillean fish traps. *Bull Mar Sci* 67:831–844
- Sandin SA, Sampaya EM, Vermeij MJA (2008) Coral reef fish and benthic community structure of Bonaire and Curaçao, Netherlands Antilles. *Caribb J Sci* 44:137–144
- ▶ Sary Z, Oxenford HA, Woodley JD (1997) Effects of an increase in trap mesh size on an overexploited coral reef fishery at Discovery Bay, Jamaica. *Mar Ecol Prog Ser* 154: 107–120
- Sheridan P, Hill R, Matthews G, Appeldoorn R (2003) The effects of trap fishing in coralline habitats: What do we know? How do we learn more? *Annu Proc Gulf Caribb Fish Inst* 54:1–12
- Stewart J (2007) By-catch reduction in wire-mesh fish traps. In: Kennelly SJ (ed) *By-catch reduction in the world's fisheries*. Springer, Dordrecht, p 75–93
- ▶ Wolff N, Grober-Dunsmore R, Rogers CS, Beets J (1999) Management implications of fish trap effectiveness in adjacent coral reef and gorgonian habitats. *Environ Biol Fishes* 55: 81–90
- Zaneveld JS (1961) The fishery resources and the fishery industries of the Netherlands Antilles. *Annu Proc Gulf Caribb Fish Inst* 14:137–171

Editorial responsibility: Ivan Nagelkerken,
Nijmegen, The Netherlands

Submitted: January 4, 2010; Accepted: August 4, 2010
Proofs received from author(s): September 10, 2010

CHAPTER 3:

Moray eels as intelligent and abundant predators on Caribbean coral reefs

Green moray eels (*Gymnothorax funebris*) appear to rapidly modify their predatory behavior to take advantage of changing feeding opportunities. During a four-month experiment in Curaçao examining methods for reducing fish trap bycatch (Johnson 2010, Chapter 2), I routinely observed green morays. For the first two months, I observed them only when caught in traps, where they took advantage of trapped prey by killing and eating their fill of other fish. Upon release from a trap one moray regurgitated five parrotfish. Morays also created piles of dead fish inside the traps, and defended these stashes, keeping dead fish under their tails in behavior that could be considered hoarding (Fig. 1a and b). After two months, morays began to follow me from trap to trap as I released fish (both live and dead) upon completion of each experimental run, as if they had learned of the opportunity for a “free lunch.” They would grab the dead fish and either eat them immediately or carry them back to reef crevices, collecting them as squirrels do acorns. These behaviors seem indicative of learning.

The abundance of green morays was also notable. Twenty-two percent of trap sets contained at least one moray, and 10% contained multiple morays (Fig 1c), with four being the greatest number observed in a single trap at one time (Fig. 1d). Within a 200m stretch of reef at 12m depth, there were often four, and frequently up to eight green morays captured among eight traps. Furthermore, the mean number of morays caught per trap set increased significantly over the experimental duration ($F_{1, 186} = 4.59$, $p < 0.05$), again suggesting learning about new food sources. These data are in stark contrast with underwater visual transects I conducted in the same areas, in which the maximum number of morays observed within a 100m stretch of reef (400m² area) was one. This implies a moray density perhaps four times greater than would be deduced from fish surveys. However,

as the home range of green morays appears to be unknown, it is unclear whether these individuals were local residents or migrants from afar.

Due to overfishing, eels may now be the top predators on many Caribbean reefs. The combination of rapid learning and great abundance indicate that they will be successful and play a key ecological role. This may be particularly true in the context of the Caribbean-wide lionfish (*Pterois volitans*) invasion. Morays have recently been observed consuming lionfish in Belize (GCFINET), and given the absence of robust grouper populations they may be key contributors to the control of lionfish abundance.

Acknowledgements

I am grateful to my research assistants for their bravery, S. Sandin and J.B.C. Jackson for comments on earlier drafts, and P. Dayton for suggesting these anecdotes were worth sharing.

Chapter 3, in full, is currently being prepared for submission for publication of the material. Johnson, Ayana Elizabeth. The dissertation author was the sole investigator and author of this material.

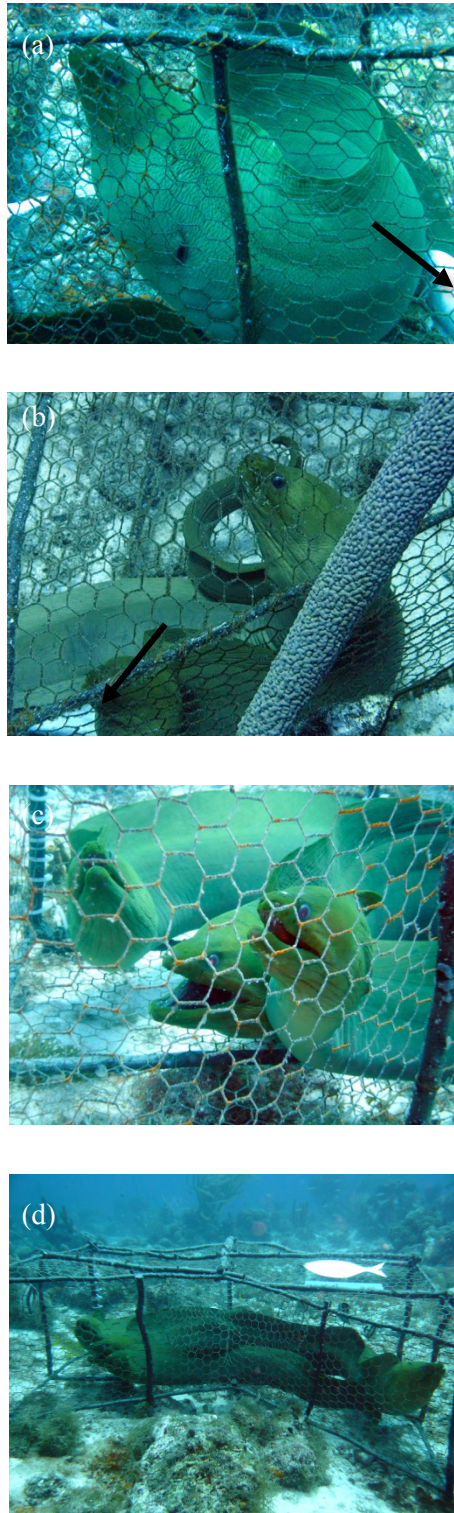


Figure 3.1. Green moray eels (*Gymnothorax funebris*) (a-b) hoarding dead fish (indicated by black arrows) under their tails, and (c-d) abundant within fish traps. Curaçao, Summer 2008.

References

Johnson, A.E. (2010) Reducing bycatch in coral reef trap fisheries: escape gaps as a step towards sustainability. *Marine Ecology Progress Series* **415**, 201-209.

GCFINET. Gulf and Caribbean Fisheries Institute Network listserver. 19 September 2010

CHAPTER 4:

Gill net use on Caribbean coral reefs is unsustainable

Abstract

Gill nets are commonly used on coral reefs around the world, yet little research has been published on their catches or the ecological effects of their use. On Curaçao, I documented the catch of 13 gill net sets by two groups of fishers. The mean catch quantity was 10.4 fish, the mean catch mass was 5.7 kg, and the mean catch value was 31.7 USD after a mean soak time of 15.3 hours. Catches were dominated by jacks (Carangidae), with bar jacks (*Caranx ruber*) the most commonly captured species. A juvenile Caribbean reef shark (*Carcharinus perezii*) was captured during this research, and fishers reported shark catch as common. Gill nets also catch rare species such as rainbow parrotfish (*Scarus guacamaia*), and have high potential for catching sea turtles and marine mammals. Fishers discarded 13% of captured fish because they were either too small or rotten. Corals and other benthos were damaged with every net set and haul. These attributes – catch of the few remaining pelagic predators on coral reefs, catch of rare species, bycatch, and benthic damage – make gill net fishing very unpopular with the large majority of the fishing community that does not use gill nets as well as with the SCUBA diving community. Few people are financially dependent on gill net fishing, gill nets have detrimental effects on coral reef ecology, and there is broad public support for regulation to restrict gill net use. Unlike many fishery management challenges, this situation is an opportunity to act for reef conservation by prohibiting future use of gill nets, while incurring minimal financial or cultural disruption to fishers. An island-wide buyout of gill nets to compensate inconvenienced fishers may be appropriate and would complement a ban.

Keywords: gill nets, coral reefs, Curaçao, Bonaire, artisanal fishing, sustainability, bycatch

Introduction

For the vast majority of the oceans where fishing occurs, for the areas not protected in marine reserves, it is important to consider the ecological effects and socioeconomic context of fishing and to examine options for achieving sustainable use. One approach is to evaluate the impacts of various types of fishing gear, and to explore how those impacts can be mitigated. This is often termed gear-based management (McClanahan and Mangi, 2004), wherein regulating the types of gears used, and the manners in which they are used, can serve as a proxy for restricting the types of fish that are caught. This can take the form of requiring gear modifications that reduce bycatch, limiting the quantity of gear used, restricting the use of certain gear types in certain areas at certain times or under certain conditions, or banning gears altogether.

Gill nets are widely used on coral reefs (Acosta and Valdes-Pizzini, 1995), yet may be the least well-studied gear type. A wealth of research has been conducted on gill net fishing in temperate waters, but few studies have been conducted in coral reef habitats. This is despite the fact that gill nets can have high levels of bycatch and can inflict great physical damage to the benthos (Mangi and Roberts, 2006).

Gill nets are typically tens to hundreds of meters in length and constructed of transparent monofilament. The nets have weights on the bottom, floats on the top, and are anchored so that they hang vertically in the water. Many fish that swim into the net but are too large to fit through the mesh are caught by their gills or are otherwise entangled as they attempt to escape. Thus, there is high bycatch; fish are caught that are neither targeted by fishermen nor desirable as food (Lewison et al., 2004). When compared with other types of fishing gear, gill nets are among those most damaging to corals (Mangi et al., 2007). Ghost fishing (i.e. fish caught by abandoned or lost fishing gear) is also a serious concern. Nets are commonly lost or abandoned, and can continue to ensnare fish for years (Breen, 1990). While biodegradable

panels and escape gaps can alleviate the respective problems of ghost fishing (Breen, 1990) and bycatch (Johnson, 2010) for fish traps, there are no equivalent simple solutions for gill nets.

Given these deleterious attributes, and the fact that gill net fishing remains unregulated on many coral reefs, I conducted what is to my knowledge the first study of gill net fishing on Curaçao, and the second quantification of fishers' gill net catches anywhere in the Caribbean. Five previous studies within the peer-reviewed literature have examined gill net fishing on Caribbean reefs. Three of those were conducted in Puerto Rico and involved experimental setting of nets (as opposed to documentation of fishers' catches). First, a 1973 study set a net for 10 days to sample the fish community and reports only the catch quantity, not biomass (Parrish, 1982). Then, two studies were conducted in 1991, one examining the effects of soak time and net size (Acosta, 1994), and the other examining the effects of net dimensions on catch composition (Acosta and Appeldoorn, 1995). In St. Lucia, a 1994 study included data on fishers' gill net catches before and after the establishment of a marine reserve (Goodridge et al., 1997). Lastly, in Martinique, a 2007 study quantified catches of experimentally set gill nets (Louis-Jean et al., 2009). An additional 12 publications present data on gill net sets conducted in Africa, the Indian Ocean, and the Pacific.

The field research I conducted augments the literature by quantifying the catches of two groups of Curaçaoan gill net fishers. Gill net fishing with hand-woven nets has been occurring on Curaçao for over 50 years, but the popularity of gill nets has burgeoned since the 1980s when monofilament nets became widely available. Currently, there are approximately 25 groups of fishers (mean group size is two fishers) on Curaçao actively using gill nets. Here, I place the catches I observed within the context of the peer-reviewed literature, present the views of interviewed fishers and professional SCUBA divers (i.e. divemasters and instructors) on measures to manage gill net fishing, and discuss justifications for restricting gill net use.

Methods

From October through December 2009, I documented the catches of two groups of gill net fishers who set their nets on the nearshore reefs of Westpunt, Curaçao (12°22'9" N, 69°9'17" W). All nets were set in the same general area, although they were not placed in the same exact position each time. The benthos of this leeward area is a fringing reef with a slope of approximately 10 degrees. Group A (two individuals, including one SCUBA diver) used a net that was 2.6 m high and 40 m wide, which they set with the lead line close to or amongst the benthos and the float line in mid-water. Group B (three individuals, including one snorkeler) used a 5 m high by 55 m wide net, which they set with the lead line in mid-water and the float line on the surface. Both nets had 5 cm by 5 cm mesh apertures. All net were set perpendicular to the shore in water 5 to 10 m deep, and were anchored to the benthos.

I requested that the fishers fish as normal, and I accompanied them as they set, checked, and hauled their nets. From their boats and using SCUBA, I observed their fishing methods, and cataloged the species and total length of each captured fish. These length data (L) in centimeters are used to calculate fish masses (W) in grams using the formula $W = aL^b$. I obtained the von Bertalanffy growth parameters a and b , as well as trophic levels for each species from FishBase (Froese and Pauly 2010). To calculate market value, I multiplied these masses (after converting to kilograms) by the average price per kilogram at which fish vendors on Curaçao purchased these species from fishers (Table 4.1).

During net sets, I also photographed incidents of benthic damage, although impacts were not quantified. If any fish were discarded, I noted the reason: undesirable species, juveniles, or rotten. The term ‘soak time’ is used to denote the number of hours the net remained in the water during a set, and was recorded to the nearest quarter hour. For each fisher group and for all net sets together, means and standard errors (SE) are presented for the soak

time (in hours), catch quantity, catch mass (kg), and catch market value (USD). Regressions were used identify correlations between soak time and number of fish caught.

To contextualize the catch compositions I observed, I compiled all peer-reviewed data for gill net catches on coral reefs. This amounted to 17 studies conducted from 1973 through 2008. It was not possible to standardize these catches by net size or soak time as those were largely unreported; however, where data permitted, catches were converted to kilograms per net set. Regressions were used to examine the relationship between study year and the mass of fish caught.

I conducted a total of 388 interviews, however, only data from interviews with 166 fishers and 197 professional divers on Curaçao and Bonaire are presented as the remaining interviewees did not respond to the questions discussed here. The interviews, conducted from September through December 2009 on Curaçao and April and May 2010 on Bonaire, provide information on the species targeted by and most frequently captured by gill nets, and on the level of key stakeholder support for managing gill net fishing. Interviewees represent approximately 63% of fishers on Curaçao, 65% of fishers on Bonaire, 86% of professional divers on Curaçao, and 83% of professional divers on Bonaire. Because no comprehensive lists exist of the fishers or divers on either island, stratified random sampling of these populations was not possible; instead, efforts were made to simply interview as many individuals as possible. χ^2 goodness-of-fit tests were used to identify significant differences in distributions of fisher and diver responses. All errors presented are standard errors.

Results

Gill Net Catches

I observed 13 gill net sets, 5 conducted by Fisher Group A and 8 conducted by Fisher Group B. Soak times ranged from 8 to 23 hours, with a grand mean of 15.3 hours (SE 0.34).

Mean soak times were not significantly different between fisher groups. Across all net sets, a total of 116 fish were captured, representing 18 species from 13 fish families (Table 4.1). Jacks (Carangidae) were by far the most commonly caught family at 75 individuals, followed by surgeonfish (Acanthuridae) at 10 individuals. The mean trophic level of all captured fish was 3.96. Two juvenile Caribbean spiny lobsters (*Panulirus argus*, Fig. 4.1a) were also captured.

The number of fish caught per set ranged from 0 to 38, with a grand mean of 10.4 (SE 2.9, Table 4.2). Capture quantity is positively correlated with net soak time ($p = 0.045$, $R^2 = 0.32$, Graph 4.1). The total mass of fish caught per set ranged from 0 to 29.9 kg, with a grand mean of 5.7 (SE = 2.2). The total estimated value of fish caught per set ranged from 0 to 169.3 USD, with a grand mean of 31.7 USD (SE = 12.6).

Some of the captured fish were discarded as bycatch because they were juveniles (Fig. 4.1a), undesirable species (Fig. 4.1b), or had rotted in the net before they were removed. Six of the captured fish were too rotten for consumption. Scorpionfish (*Scorpaena plumieri*), peacock flounder (*Bothus lunatus*), and bonefish (*Albula vulpes*) were considered bycatch by both groups of fishers. Surgeonfish (*Acanthurus spp.*) were considered bycatch by Group A. All told, 13% of the total catch was discarded. Two rare species were captured: a rainbow parrotfish (*Scarus guacamaia*, Fig. 4.1c) and a reef shark (*Carcharinus perezii*, Fig. 4.1d).

For the 17 studies from the literature, catches per set ranged from ~1kg in Puerto Rico in 1990 to 89 kg in the Seychelles in 1986, with a mean of 16.7 kg and median of 11.0 kg (Graph 4.2, Table 4.3). When averaged over region, Africa and the Indian Ocean had the highest mean catch per set at 22.0 kg, followed by the Pacific at 13.1 kg, and the Caribbean at 12.1 kg. The mean soak time used by fishers was 9.9 hours. Herrings (Clupeidae), parrotfish (Scaridae), and jacks were the families most commonly mentioned as dominating the catches. For two studies, sharks (Carcharinidae) were the largest contributors to catch mass (Acosta, 1993, Pet-Soede et al., 2001b).

The global gill net catch per set in coral reef fisheries is negatively correlated with research year ($p = 0.014$, $R^2 = 0.23$, Graph 4.2), a trend that remains significant even when the very high catch reported from the Seychelles is omitted from the calculation ($p = 0.033$, $R^2 = 0.19$). However, the sparseness of the data, the effects of varied physical and biological oceanographic factors, and local fishing histories are important caveats to the robustness of this relationship.

There were three types of fisher-benthos-net interactions that resulted in habitat damage. First, both fisher groups used gorgonians (Fig. 4.1e) and coral heads (Fig. 4.1f) as anchors for tying off the ends of their nets, and allowed nets to become entangled in the benthos. Second, the diver from Group A and the snorkeler from Group B repeatedly touched corals and other parts of the benthos with their hands and kicked it with their fins (Fig. 4.1g). Third, fishers stirred up sediment that then settled on benthic organisms. All three of these fisher-benthos interactions occurred on every net set and haul. On each net haul, both living and dead benthic organisms were hauled up with the net. This was due in part to fishers in the boat retrieving the net from the surface without waiting for the diver or snorkeler to disentangle it. An abandoned net was observed near the location of one net set by Group B (Fig. 4.1h shows part of this net). Group B members confirmed that it was their net and explained that they had abandoned it after it was damaged during Tropical Storm Omar in October 2008. At the time I observed the net it had been tangled on the reef for 13 months.

Interview Responses

In addition to the gill net fishers I directly observed, I interviewed 17 current and 4 former gill net fishers. On Curaçao, I interviewed 17 gill net fishers from 10 different fisher groups, and on Bonaire 4 fishers from 3 different fisher groups. These interviewees represent approximately 40% of gill net fishers on Curaçao, and an unknown portion of those on Bonaire.

Gill net fishing is reportedly common among Asian fishers. Unfortunately, I was not able to obtain interviews with any Asian fishers, so their methods, catches, and views are not reported here. While it is hearsay, Curaçaoan fishers conveyed dismay at the gill-netting practices used by Asian fishers with respect to the high catch of juveniles and herbivores, especially associated with setting nets in bays. One Curaçaoan fisher remarked, “We were so stupid to teach the Chinese how to use the nets - they waste a lot. They destroy. And they eat all the parrotfish.”

Among the gill net fishers I did interview, all but two reported setting their nets on the reefs. Nets were reported to range in cost from 86 USD to 686 USD, with a mean of 300 USD. Fishers set these nets with frequencies from twice a week to three times a year. Mean reported soak times were from 8 hours to 3 days, with 1 day being the most common soak time. Most fishers mentioned checking net contents periodically if set times were over 12 hours. The most desired species were bar jacks (*Caranx ruber*), schoolmaster snappers (*Lutjanus apodus*), horse-eye jacks (*Caranx latus*), and mutton snappers (*Lutjanus analis*, Table 4.4). One fisher named turtles as his most desired catch. The most commonly caught species were parrotfish (Scaridae), bar jacks, and horse-eye jacks.

Interviewed gill net fishers were asked about the biggest fish they ever caught in a gill net. Eleven fishers reported sharks as their largest, two reported yellowtail snappers (*Ocyurus chrysurus*), two reported horse-eye jacks, one reported an amberjack (*Seriola dumerili*), and the others could not recall. Those gill-netted sharks included seven hammerheads (*Sphyrna zygaena*), three tiger sharks (*Galeocerdo cuvier*), and one nurse shark (*Ginglymostoma cirratum*). They reportedly ranged in length from 150 cm to 350 cm with a mean of 237 cm, and ranged in weight from 30 kg to 196 kg with a mean of 139 kg. One fisher remarked that two out of ten times he sets a net he catches a shark. Every gill net fisher uses other types of fishing gear (i.e. bottom line fishing, trolling, snorkel) in addition to nets. There were only two fishers for

whom gill nets were the primary type of gear used, and those were also the only two fishers who considered gill nets to be the most profitable type of fishing gear to use.

The interviews I conducted with fishers and professional divers show popular support on both islands for restricting gill net use. Requiring a minimum mesh size for gill nets received support from 85% of fishers and 94% of professional divers (Table 4.5). Banning the use of gill nets on coral reefs was supported by 64% of fishers and 98% of divers, with seven divers noting the catch of turtles, dolphins, and/or sharks as their rationale. However, there is less support for a complete island-wide ban of gill nets; 47% of fishers and 78% of divers support a total ban. Whether calculated for each island separately or for all interviewees collectively, divers were significantly more likely than fishers to support each of these three restrictions (all $p < 0.0001$). Of those supported gear bans as a management approach, 44% of divers and 38% of fishers named gill nets as their first choice of gear to ban, making them the most popular choice.

Nine of the gill net fishers reported having had their nets damaged multiple times, damage they attribute to divers. Ten of the gill net fishers also use (or formerly used) fish traps, and all of them reported having had their traps damaged on multiple occasions. Of all the trap fishers I interviewed, 79% reported having incurred trap damage they attribute to divers. Of the professional divers I interviewed, 16% admitted having either released fish from or damaged a gill net, and 36% admitted the same for fish traps. Two divers recounted having released turtles caught in gill nets.

Discussion

Because of the unpopularity of gill net fishing, fishers were very reluctant to have their methods or catches observed, thus I was only able to identify two fisher groups willing to allow me to document their activity. Considering the degree of secrecy and uncertainty that surrounds this fishery, and the dearth of data on fishers' gill net catches in the Caribbean, even this small

amount of data that I was able to collect is informative. It is unclear whether the composition of the catches reported here are similar to catches made by other groups of fishers on other parts of the island, but they are certainly examples of some part of the range of possible catches.

Data collected from gill nets set on the shallow coral reefs of Curaçao show catches dominated by top predators and accompanied by damage to corals and other benthos. The mean catch mass of 5.7 kg set is low in comparison to the mean across the literature, and low compared to catches in St. Lucia in the mid 1990s, but higher than values reported for Puerto Rico in the early 1990s. Similar to other studies around the world, jacks, and pelagic predators more generally, were an important part of the catch.

Although the small sample size of this study necessitates judicious interpretation, I draw upon the available literature to elucidate the implications of continued gill net fishing. Catches on Curaçao may seem low enough to be benign, and the high selectivity for carnivores may seem to be a positive attribute, but a further look at the catch composition and habitat effects indicate otherwise. There are four primary characteristics that contribute to the unsustainability of gill net use on Caribbean coral reefs. Gill nets (1) catch the few remaining pelagic predators on coral reefs, (2) catch rare species, (3) produce moderate bycatch, and (4) cause benthic damage.

Predator catch

Caribbean reefs are notoriously depauperate of predators. On most islands, large groupers and snappers are now rare (Pandolfi et al., 2003). Sharks are similarly rare, and Caribbean reef sharks (*C. perezii*) are categorized as being “near threatened” with extinction (Rosa et al., 2006). No sharks were sighted in extensive surveys of Curaçao’s fish population conducted in 2000 (Sandin et al., 2008b) and 2009 (A.E.J, unpublished data). Despite these facts, the mean trophic level of fish caught in this study was almost four, that of a carnivore

eating other carnivores. Gill nets seem to selectively catch pelagic predators. In over 250 dives I conducted on the leeward side of Curaçao between 2007 and 2010, the only shark I ever encountered was the juvenile reef shark I observed dead in a gill net during this study.

Anecdotes from interviewed divers, including one who reported that he has only seen three sharks in 30 years of diving, further bolster this assertion of the rarity of sharks on Curaçao's reefs. All interviewed gill net fishers reported catching sharks with some regularity. Catch of sharks in gill nets is also high in other locations, such as Trinidad and Tobago where gill nets account for 90% of shark landings and sharks are considered incidental catch (Shing, 1995).

Historical documents indicate that sharks were among the most common types of fish in the Caribbean (Ward-Paige et al., 2010). In the mid 1800s, juvenile sharks were abundant in Jamaican coastal waters, and net fishing caught well over 10,000 of them annually (Hardt, 2008). It is also telling that gill net research conducted in Puerto Rico in 1991 removed sharks and rays *before* quantifying the catch (Acosta and Appeldoorn, 1995) because they were caught in greater abundance than any other types of fish and masked other trends in the data (Acosta, 1993). Sharks are considered vulnerable even to light fishing pressure (Ferretti et al., 2010), and primarily due to exploitation are largely absent from modern coral reefs (Ward-Paige et al.). Sixteen of the 36 shark species in the Caribbean, including the hammerheads and tiger sharks mentioned by fishers as common in gill net catches, are considered either endangered or vulnerable to extinction, with an additional eight species classified as near threatened (IUCN, 2010).

Jacks, the most commonly captured fish family, are also apex predators. The catch of jacks in gill nets was disproportionately high relative to their abundance in underwater visual surveys of fish populations (A.E.J., unpublished data). In the absence of significant populations of sharks and large groupers and snappers, jacks may now be the most ecologically significant pelagic predator on Curaçao's reefs, making their high catch in gill nets notable. If gill net

fishing effort continues to increase, jack populations will likely decrease, perhaps leaving moray eels (Muraenidae) as the most abundant remaining reef predator (see Chapter 3).

This situation on Caribbean reefs is in stark contrast with that of pristine coral reefs, where the fish biomass is known to be dominated by top predators and sharks can comprise over 70% of reef fish biomass (Sandin et al., 2008a). Functionally removing pelagic predators is risky as it undermines ecological stability and alters trophic dynamics, likely reducing resilience. Trophic cascading effects associated with predator removal have been documented in the northwest Atlantic (Myers et al., 2007).

Rare species

Gill nets catch rare species with surprising frequency. One of the fish captured during this research was a rainbow parrotfish. Not only is this species so rare as to have avoided detection in both the 2000 and 2009 fish surveys conducted on Curaçao (Sandin et al., 2008b, A.E.J. unpublished data), it was also until recently considered vulnerable to extinction (its extinction risk is now considered unknown due to insufficient data, Ferreira et al., 2008).

Gill nets are one of the primary means by which sharks and sea turtles are captured (Lewison et al., 2004). Sea turtle bycatch in the Dominican Republic has been estimated at one turtle per day (Aucoin and León, 2008). During interviews, one fisher mentioned targeting turtles, and two divers mentioned seeing and releasing turtles entangled in nets. This is of concern because both green and hawksbill turtles, which are present on Curaçao, are at less than 0.5% of their historical abundances (McClenachan et al., 2006), and are respectively considered endangered and critically endangered (IUCN, 2010).

Bycatch

Bycatch can be defined as discarded plus incidental catch (Alverson et al., 1994). By this metric, more than one out of every ten fish caught by gill nets during this research was bycatch. It is important to note that what one categorizes as bycatch is not universal. Cultural preferences often dictate which species of fish are eaten. For example, some individuals consider parrotfish, scorpionfish, and sharks to be bycatch, while others target them for food. However, any species can become bycatch by virtue having been left in the net too long. Bycatch fish in this study were almost evenly split between those discarded because they were too small or too damaged, and those discarded because they were undesirable species.

Divers expressed concern about the possibility of gill nets catching dolphins. Among the fishers I interviewed, there was unanimous agreement that marine mammals are bycatch, and no one reported having captured one. While catch of marine mammals was neither mentioned by fishers nor observed by divers, occurrences are fairly frequent in other locations. Globally, gill nets are the single greatest cause of marine mammal bycatch (Lewison et al., 2004), and such bycatch is common throughout the Caribbean (Vidal et al., 1994), although regional quantifications of this bycatch do not yet exist (Bjorkland et al., 2007). The high potential for turtle and marine mammal entanglement in gill nets is notable considering catch of these taxa is illegal on Curaçao.

Habitat Damage

The images in Figure 1 show how gill net use can damage coral reef benthos. Previous studies have reported benthic destruction caused by bottom-set gill nets (Ohman et al., 1993) and categorized gill nets as second only to spearguns in the amount of habitat damage they cause (Mangi and Roberts, 2006). Considering the ubiquitous decline in coral cover throughout the Caribbean (Gardner et al., 2003) and the 45% decline in coral cover on the shallow reefs of

Curaçao between 1973 and 2003 (Bak et al., 2005), this is cause for concern. This concern is heightened given the increasing frequency of coral bleaching associated with global warming, and the myriad other threats (e.g. acidification, sedimentation, pollution) corals face (Hoegh-Guldberg and Bruno, 2010). In light of this, reducing the benthic damage caused by fishing gear is increasingly important.

Gill nets vs. fish traps

Gill net fishing clearly has negative effects on coral reef ecosystems, but there is also the question of how gill net use may benefit fishers. Fishers' primary reasons (not mutually exclusive) for adopting this gear type were that (1) it has become difficult to catch fish with lines, (2) they don't have large enough boats and/or powerful enough motors to go offshore to fish for pelagic species, (3) they used to use traps but divers commonly destroy traps, (4) and nets are easier to maintain and often less expensive to replace than traps. The first reason is very telling. Fishers report that where it was once easy to throw a line and catch a fish, it now takes a net to catch enough to make a living. This, along with the implication of the second reason that they feel they need to go offshore to make a decent catch, actually provides a rationale for restricting gill net fishing: gill nets are catching what few fish are left on shallow reefs. The third reason is somewhat ironic because divers destroy fishers' gear out of a desire to protect reef fish populations, but that may have the unintended consequence of increasing the use of gill nets, which are potentially just as ecologically damaging, if not more so, than traps. The fourth reason implies the need for market and/or regulatory mechanisms to manage gill net use.

The trend of fish traps being replaced by nets is not exclusive to Curaçao. In Puerto Rico and the U.S. Virgin Islands, the proportion of reef fish landings caught with traps has decreased over 50%, with a concurrent increase in net catches in recent years (Agar et al., 2008). In light of this trend, it is informative to compare the catch characteristics of traps and

gill nets. Gill net catches on Curaçao are dominated by nearshore pelagic predators, namely jacks. Fish trap catches on Curaçao are dominated by herbivores, namely parrotfish (Johnson, 2010). A gill net catches 2.6 times more kilograms of fish per set than a trap, and because those netted fish are of higher market value, that results in a catch value 4.8 times greater (Table 4.6). Based on these mean gear costs and catch values, a gill net pays for itself after having been used 10.8 times, and a trap pays for itself after 5.2 uses. It seems the potential profits are lucrative enough to overcome the significant social ostracism associated with gill net use.

Banning gill nets

Over a decade ago, the fishery department of Curaçao drafted an ordinance that would ban the use of gill nets in water >60 m, restrict net and mesh size, and prohibit gill nets from being left to fish unattended. The ban on use in shallow water would become effective five years after the legislation passed. Because of the harmful impacts gill nets can have on fish and benthic communities, the use of gill nets should be carefully assessed and potentially phased out in less than the proposed five years. There is currently a law that prohibits the catch of sea turtles and marine mammals, and as gill nets are the fishing gear most likely to catch these taxa, it would be a logical extension of that prohibition to restrict gill net use.

There is clear public support for regulatory action to restrict gill net fishing, and that support has notably increased in recent years. The survey responses I obtained indicate a more than doubling since 1995 of the number of fishers who believe net fishing should be limited in order to improve fishery management (Debrot and Nagelkerken, 2000). It appears that in the 14 years between these sets of interviews, the fishing community has become increasingly concerned with the effects of gill net fishing. Considering how few fishers use gill nets, it is not surprising that the majority of them would like to see that gear restricted. Divers are nearly unanimous in their desire to ban gill net use on reefs. The intense diver distaste for gill nets that

sometimes leads to vandalism is not unique to Curaçao and has been documented in other Caribbean locations as well (Goodridge et al., 1997).

This may be the ideal situation for a buyout of the fishery. For a relatively small sum of money, all gill nets on the island could be purchased from fishers, compensating them for the loss of revenue. This would complement a ban in that it would remove the gear from circulation, expedite a phase-out, and perhaps reduce the incidence of future illegal activities. Buybacks are useful tools for reducing fishing capacity, preventing the overexploitation of fish stocks, smoothing management transitions, and for promoting conservation more generally (Groves and Squires, 2007). The economic concept behind buybacks is that fishermen should not have to pay the costs of regulatory change when the benefits of that regulation are what can be termed “an ecological public good” (Groves and Squires, 2007). Such a buyout would have to be simultaneously enacted with an island-wide ban on the sale of gill nets.

The number of fishers using gill nets is presently quite low, although that number seems to be increasing. One fisher remarked, “I might start using gill nets because things are getting bad and I have boat payments.” Reducing gill net use will have positive effects on fishery sustainability that can be expected to benefit fishers who utilize other types of fishing gear (Mangi and Roberts, 2006). This is perhaps particularly true for hook-and-line fishers utilizing shallow reef areas. Although net fishers tend to be more dependent on fishing than other groups of fishers (Acosta and Valdes-Pizzini, 1995), all gill net fishers on Curaçao also use other types of fishing gear. Thus, while a gill net ban would affect their incomes, it is unlikely to be financially devastating. In fact, most gill net fishers do not consider gill net fishing to be the most profitable gear to use. The small but growing number of gill net fishers is rising in tandem with public support to restrict gill net use, providing the opportunity to curtail this trend with a ban that would have minimal costs for fishers but potentially large benefits for fishery sustainability. It is somewhat rare that fishers and divers agree on coral reef management

measures, and this opportunity to restrict ecologically detrimental fishing with the support of two key stakeholder groups should not be squandered.

Acknowledgements

I extend my gratitude to the fishers who allowed me to accompany them, and to dive buddies K. Withy-Allen, and K. Marhaver. J. Jackson, S. Sandin, J. Smith, and L. Levin provided helpful comments on earlier drafts. A. Alcala and T. McClanahan generously provided unpublished data to complement their published research. Funding was provided by an NSF Graduate Research Fellowship, a Switzer Foundation Fellowship, an AAUW Fellowship, and the Scripps Institution of Oceanography.

Chapter 4, in full, has been submitted for publication of the material. Johnson, Ayana Elizabeth. The dissertation author was the sole investigator and author of this material.

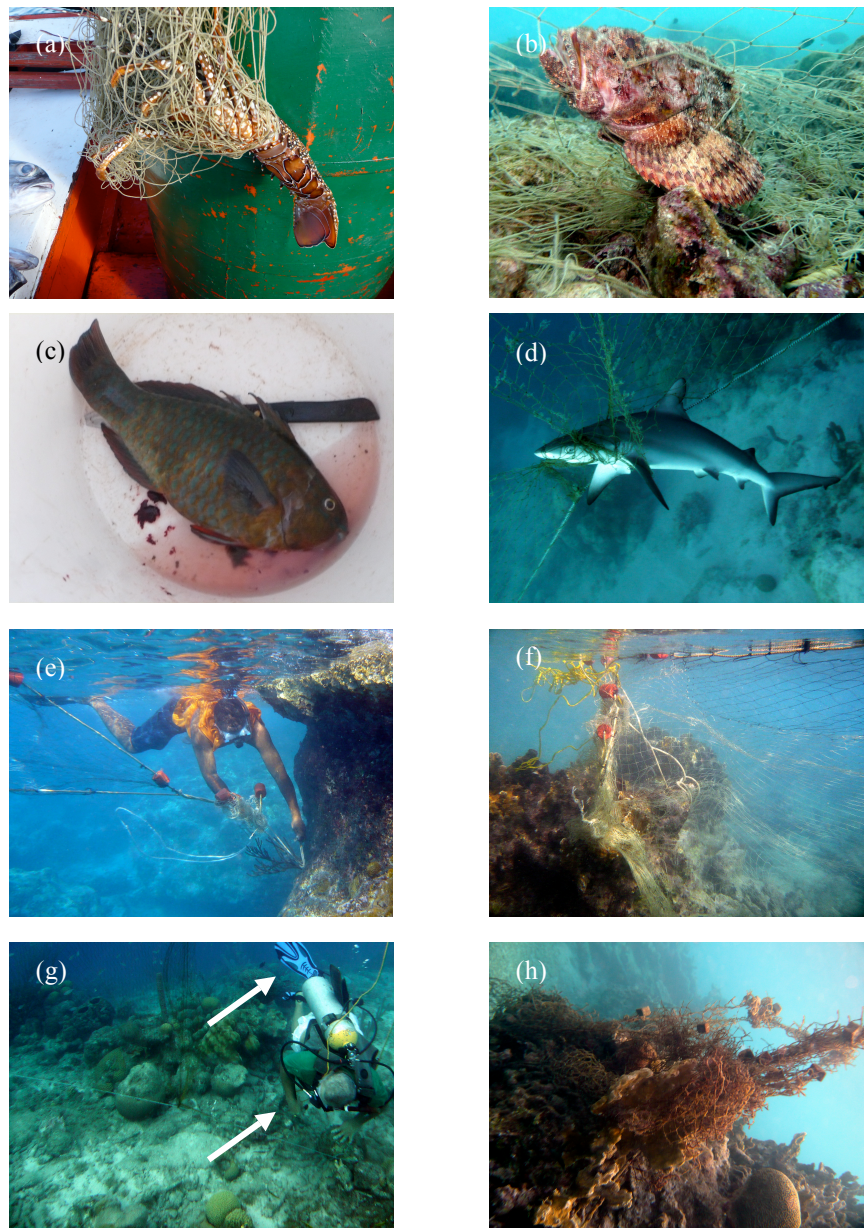


Figure 4.1. Gill net bycatch includes (a) juveniles (Caribbean spiny lobster, *Panulirus argus*) and (b) undesirable species (scorpionfish, *Scorpaena plumeri*). Rare species captured were (c) a rainbow parrotfish (*Scarus guacamaia*) and (d) a reef shark (*Carcharinus perezii*). Gill net interactions with benthos included using (e) gorgonians (denoted by arrow) and (f) corals to anchor nets, and allowing nets to become tangled in coral, (g) touching and kicking by fishers (noted by arrows), and (h) abandoning damaged nets on the reef (this image has been rotated 90° right).

Table 4.1. Total number, mass, and mean market value of each species captured by gill nets.

Family	Species	Total Number	Total Mass (kg)	Market Value (\$/kg)
Acanthuridae	<i>Acanthurus chirurgus</i> (surgeonfish)	1	0.1	3.10
	<i>Acanthurus coeruleus</i> (blue tang)	9	1.3	
Albulidae	<i>Albula vulpes</i> (bonefish)	1	1.3	0.00
Bothidae	<i>Bothus lunatus</i> (peacock flounder)	2	0.4	0.00
Carangidae	<i>Caranx latus</i> (horse-eye jack)	13	18.2	5.90
	<i>Caranx ruber</i> (bar jack)	62	29.0	
Carcharhinidae	<i>Carcharinus perezii</i> (Caribbean reef shark)	1	5.9	6.30
Gerreidae	<i>Gerres cinereus</i> (yellow fin mojarra)	4	0.3	3.20
Haemulidae	<i>Haemulon carbonarium</i> (Caesar grunt)	1	0.1	3.20
	<i>Haemulon sciurus</i> (bluestriped grunt)	2	1.0	
Kyphosidae	<i>Kyphosus incisor</i> (Bermuda chub)	2	2.4	3.50
Lutjanidae	<i>Lutjanus apodus</i> (schoolmaster snapper)	5	3.0	5.90
Priacanthidae	<i>Heteropriacanthus cruentatus</i> (glasseye snapper)	2	6.2	5.90
Scaridae	<i>Sparisoma aurofrenatum</i> (redband parrotfish)	1	0.2	2.80
	<i>Scarus guacamaia</i> (rainbow parrotfish)	1	0.4	
	<i>Sparisoma viride</i> (stoplight parrotfish)	1	0.7	
Scorpaenidae	<i>Scorpaena plumeri</i> (spotted scorpionfish)	4	1.5	0.00
Sphyraenidae	<i>Sphyraena barracuda</i> (great barracuda)	1	1.7	5.60
Panuliridae	<i>Panulirus argus</i> (Caribbean spiny lobster)	2	0.8	20.00
Grand Total		116	73.7	

Table 4.2. Soak time, catch quantity, catch biomass, and catch value for all net sets by fisher groups A and B. Means with standard errors (SE) are presented for each fisher group as well as for all net sets observed (grand mean).

	Net Set #	Soak Time (hrs)	Catch quantity (#)	Catch biomass (kg)	Catch Value (USD)
Fisher Group A	1	23.0	9	10.9	66.2
	2	23.0	38	29.9	169.3
	3	14.5	20	8.5	50.3
	4	14.5	20	2.4	14.3
	5	8.0	10	2.9	16.8
	<i>Mean</i>	<i>16.6</i>	<i>19.4</i>	<i>10.9</i>	<i>63.4</i>
	<i>(SE)</i>	<i>(2.8)</i>	<i>(5.2)</i>	<i>(5.0)</i>	<i>(28.3)</i>
Fisher Group B	6	14.5	7	5.3	23.9
	7	13.5	1	0.7	4.4
	8	14.0	1	0.5	2.8
	9	14.5	7	3.2	14.5
	10	14.75	13	4.1	12.9
	11	15.0	7	4.2	29.6
	12	14.0	0	0	0
	13	15.0	2	1.9	11.0
	<i>Mean</i>	<i>14.4</i>	<i>4.8</i>	<i>2.5</i>	<i>12.4</i>
	<i>(SE)</i>	<i>(0.2)</i>	<i>(1.6)</i>	<i>(0.7)</i>	<i>(2.6)</i>
<i>Grand Mean</i>		<i>15.3</i>	<i>10.4</i>	<i>5.7</i>	<i>31.7</i>
<i>(SE)</i>		<i>(0.34)</i>	<i>(2.9)</i>	<i>(2.2)</i>	<i>(12.5)</i>

Table 4.3. CPUE, commonly caught fish families, sample size (N), mean soak time in hours (h) or days (d), mean net size in meters (m), mean mesh size (cm), data type (experimental fishing (E) or catch surveys (C)), and reference for gill net fishing research in coral reef habitats ordered by region, location, and year. For the studies extending a few months into the subsequent year, start year is listed. Where multiple net sizes were studies, the mean size is listed. ^a Study omitted sharks and rays from the catch quantification. ^b Year of research not reported, so listed as 1 year before publication.

Location	Year	Mean CPUE	Common Families	N	Soak Time	Net Size (m)	Mesh Size	Data Type	Reference
Caribbean	Puerto Rico	1973	15 fish/day	Carangidae	6	10 d	7.0 x 2.2	2.54 5.08	E (Parrish, 1982)
				Labridae					
				Haemulidae					
	Puerto Rico	1990	1.0 kg/set ^a	Carcharhinidae					(Acosta and Appeldoorn, 1995, Acosta, 1993)
				Dasyatidae	292	12 h	50 x 1.75	m: 9.8	E
				Haemulide					
				Scaridae					
	Puerto Rico	1991	37 fish/day 3.6 kg/set	Scaridae	12	24 h	366 x 2	7.6	E (Acosta, 1994)
	St. Lucia	1994 1995	31.1 kg/set 33.6 kg/set		130 13	8.5 h 11.8 h			(Goodridge et al., 1997)
	Martinique	2007 ^b	6.3 kg/set 3.6 kg/set		18 18	5 h	300 x 2.5	4.5	(Louis-Jean et al., 2009)
Africa and the Indian Ocean	Curaçao	2009	5.7 kg/set	Carangidae Acanthuridae	13	15.3 h	50 x 3.8	5.0	C present study
	Seychelles	1986	89 kg/set						(Laroche and Ramanarivo, 1995)
	Mauritius	1986	14.8 kg/set						(Laroche and Ramanarivo, 1995)
	Kenya	1984	33 kg/set						(Laroche and Ramanarivo, 1995)
	Kenya	1995	22.6 kg/set		10				(McClanahan et al., 1997)

Table 4.3 continued.

Location	Year	Mean CPUE	Common Families	N	Soak Time	Net Size (m)	Mesh Size	Data Type	Reference
Kenya	1998	9.1 kg/set 8.1 kg/set		72 20				C	(McClanahan and Mangi, 2000)
Kenya	1998 2000	~14 kg/set	Scaridae Siganidae Lethrinidae			~25 x 1.5	6.0	C	(McClanahan and Mangi, 2004)
Madagascar	1989	17.2 kg/set	Gerreidae Lethrinidae Clupeidae		~10 h	225 x 2.3	m: 4.8	C	(Laroche and Ramanarivo, 1995)
Madagascar	1991	~25.1 kg/set 11.4 kg/fisher/set						C	(Laroche et al., 1997)
Madagascar	2008	3.4 kg/fisher	Clupeidae Pomacentridae					C	(Davies et al., 2009)
Mozambique	1996	5.3 kg/set 3.6 kg/fisher/set	Gerreidae Platycephalidae Sillaginidae	119				C	(de Boer et al., 2001)
Philippines	1991	7.5 kg/set 0.43 kg/fisher/set	Caesionidae Siganidae Acanthuridae	140	5.8 h	200m x 10m	m :7.5	C	(Amar et al., 1996)
Hawaii	1993	1.25 kg/hr		26				C	(Friedlander and Parrish, 1997)
Indonesia	1996	17.5 kg/set	Clupeidae Carangidae	282				C	(Pet-Soede et al., 2001a)
Indonesia	1997	4.3 kg/set 24.1 kg/set 4.0 kg/set 23kg/set	Carcharhinidae	49 11 7				C	(Pet-Soede et al., 2001b)
Thailand	2002	6.2 kg/set	Clupeidae Mugilidae		2 h	510 x 3.25		C	(Lunn and Dearden, 2006)

Table 4.4. Species most desired and most frequently caught by gill net fishers on Curaçao. Fishers were not limited in the number of species they could list in either category.

	Most desired Species	Most Frequently Caught Species
<i>Caranx ruber</i> (bar jack)	15	7
<i>Lutjanus apodus</i> (schoolmaster snapper)	11	3
<i>Caranx latus</i> (horse-eye jack)	9	5
<i>Lutjanus analis</i> (mutton snapper)	8	2
<i>Ocyurus chrysurus</i> (yellowtail snapper)	3	1
<i>Lutjanus mahogoni</i> (mahogany snapper)	3	2
<i>Lutjanus griseus</i> (grey snapper)	4	2
<i>Scarus</i> and <i>Sparisoma</i> spp. (parrotfish)	3	6
<i>Panulirus argus</i> (spiny lobster)	3	
<i>Sphyraena barracuda</i> (barracuda)	2	2
<i>Seriola dumerili</i> (amberjack)	2	
turtles (unspecified taxa)	1	
<i>Thunnus obesus</i> (bigeye tuna)	1	
<i>Thunnus albacares</i> (yellowfin tuna)	1	
<i>Istiophorus albicans</i> (sailfish)	1	
<i>Lutjanus campechanus</i> (red snapper)	1	
<i>Centropomus undecimalis</i> (snook)	1	3
<i>Acanthurus</i> spp. (surgeonfish)	1	2
<i>Paranthias furcifer</i> (creolefish)	1	
<i>Manta birostris</i> (manta ray)	1	
<i>Gerres cinereus</i> (yellowfin mojarra)	1	
<i>Mugil curema</i> (white mullet)	1	2
shark (unspecified taxa)		1
<i>Lachnolaimus maximus</i> (hogfish)		1
<i>Haemulon</i> spp. (grunt)		2

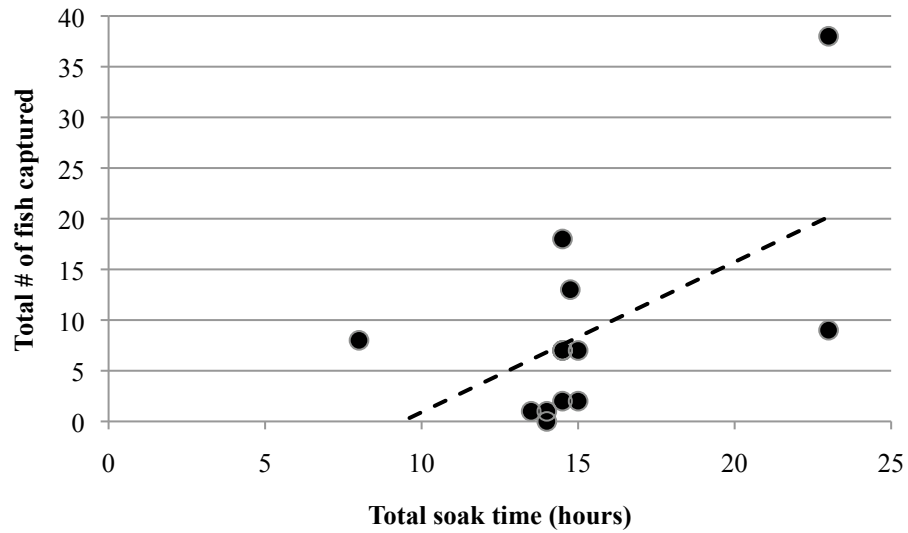
Table 4.5. Percentages of interviewed fishers and professional SCUBA divers who responded “yes” to questions about potential regulations for gill net fishing.

	Fishers			Divers			Total
	Curaçao (N = 119)	Bonaire (N = 47)	Overall (N = 166)	Curaçao (N = 105)	Bonaire (N = 92)	Overall (N = 197)	All interviewees (N = 363)
Require a minimum mesh size for gill nets?	86%	81%	85%	97%	90%	94%	90%
Ban gill net use on the coral reefs?	61%	72%	64%	99%	98%	98%	82%
Ban gill net use in all waters of the island?	45%	54%	47%	72%	87%	78%	63%

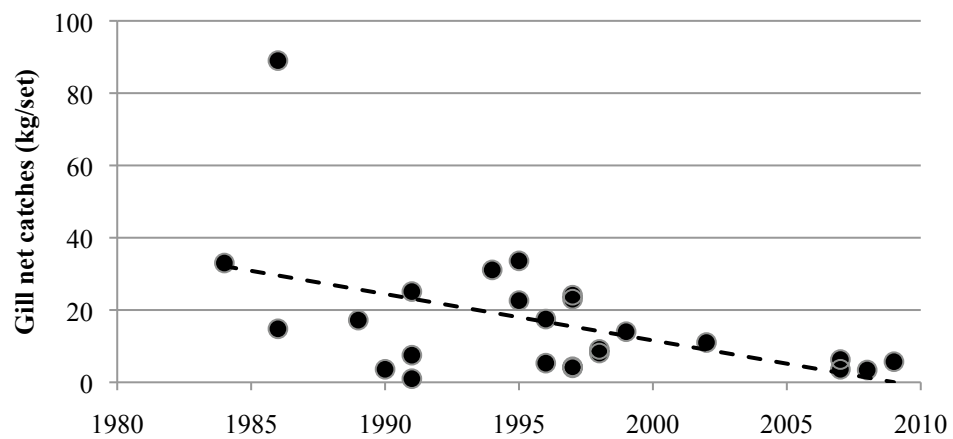
Table 4.6. Characteristics of gill net catches in 2009 and fish trap catches in 2008 on Curaçao.

	Gill Nets	Fish Traps
Mean # of fish caught	10.4	11.8
Mean fish length (cm)	25.9	18.4
Mean catch mass (kg)	5.7	2.2
Mean catch value (USD)	27.90	5.80
Cost for 1 unit of gear (USD)	~300	~30

Graph 4.1. Soak time versus number of fish captured by two groups of fishers on Curaçao. ($p = 0.045$, $R^2 = 0.32$)



Graph 4.2. Catch-per-unit-effort (CPUE) of gill nets by year for all catches reported in the peer-reviewed literature. ($p = 0.014$, $R^2 = 0.23$; see Table 4.3 for details.)



References

- Acosta, A., Valdes-Pizzini, M. (1995) Comparison of catch rates, catch composition and operations of gillnets and trammel nets in coral reef areas with notes on the socio-economic aspects of the fishery. *Proceedings of the Gulf and Caribbean Fisheries Institute* **47**, 141-158.
- Acosta, A.R. (1993) Factors influencing gillnet and trammel net selectivity on a Caribbean coral reef. Ph.D. Dissertation. University of Puerto Rico, 174 pages.
- Acosta, A.R. (1994) Soak time and net length effects on catch rate of entangling nets in coral reef areas. *Fisheries Research* **19**, 105-119.
- Acosta, A.R., Appeldoorn, R.S. (1995) Catching efficiency and selectivity of gillnets and trammel nets in coral reefs from southwestern Puerto Rico. *Fisheries Research* **22**, 175-196.
- Agar, J.J., Waters, J.R., Valdes-Pizzini, M., *et al.* (2008) US Caribbean fish trap fishery socioeconomic study. *Bulletin of Marine Science* **82**, 315-331.
- Alverson, D.L., Freeberg, M.H., Murawski, S.A., Pope, J.G. (1994) A global assessment of fisheries bycatch and discards. FAO Fisheries Technical Paper. No. 339. Rome, FAO, 233.
- Amar, E.C., Cheong, R.M.T., Cheong, M.V.T. (1996) Small-scale fisheries of coral reefs and the need for community-based resource management in Malalison Island, Philippines. *Fisheries Research* **25**, 265-277.
- Aucoin, S., León, Y.M. (2008) Preliminary data on Hawksbill turtle (*Eretmochelys imbricata*) bycatch in an artisanal gillnet used near Jaragua National Park, Dominican Republic. *Proceedings of the Gulf and Caribbean Fisheries Institute* **60**, 169-172.
- Bak, R., Nieuwland, G., Meesters, E. (2005) Coral reef crisis in deep and shallow reefs: 30 years of constancy and change in reefs of Curacao and Bonaire. *Coral Reefs* **24**, 475-479.
- Bjorkland, R., Crowder, L.B., Eckert, K.L., *et al.* (2007) A summary review of wider Caribbean fisheries and their relationships to sea turtles, marine mammals and seabirds. *Proceedings of the Gulf and Caribbean Fisheries Institute* **59**, 391-393.
- Breen, P.A. (1990) A review of ghost fishing by traps and gillnets. *Proceedings of the Second International Conference on Marine Debris. NOAA Technical Memo*, 571-599.
- Davies, T.E., Beanjara, N., Tregenza, T. (2009) A socio-economic perspective on gear-based management in an artisanal fishery in south-west Madagascar. *Fisheries Management and Ecology* **16**, 279-289.

- de Boer, W.F., van Schie, A.M.P., Jocene, D.F., Mabote, A.B.P., Guissamulo, A. (2001) The impact of artisanal fishery on a tropical intertidal benthic fish community. *Environmental Biology of Fishes* **61**, 213-229.
- Debrot, A.O., Nagelkerken, I. (2000) User perceptions on coastal resource state and management options in Curaçao. *Revista de Biologia Tropical* **48**, 95-106.
- Ferreira, C.E., Ferreira, B., Rocha, L.A., Gaspar, A.L., Feitosa, C., Choat, J.H. (2008) *Scarus guacamaia*. In: IUCN 2010. IUCN Red List of Threatened Species. Version 2010.4. <www.iucnredlist.org>. Downloaded on 03 December 2010.
- Ferretti, F., Worm, B., Britten, G.L., Heithaus, M.R., Lotze, H.K. (2010) Patterns and ecosystem consequences of shark declines in the ocean. *Ecology Letters* **13**, 1055-1071.
- Friedlander, A.M., Parrish, J.D. (1997) Fisheries harvest and standing stock in a Hawaiian bay. *Fisheries Research* **32**.
- Froese, R., Pauly, D. Editors. 2010. FishBase. World Wide Web electronic publication. www.fishbase.org, version (09/2010).
- Gardner, T., IM, C., Gill, J., Grant, A., Watkinson, A. (2003) Long-term region-wide declines in Caribbean corals. *Science* **301**, 958-960.
- Goodridge, R., Oxenford, H.A., Hatcher, B.G., Narcisse, F. (1997) Changes in the shallow reef fishery associated with implementation of a system of fishing priority and marine reserve areas in Sufriere, St. Lucia. *Proceedings of the Gulf and Caribbean Fisheries Institute* **49**, 316-229.
- Groves, T., Squires, D. (2007) Lessons from fisheries buybacks. In: *Fisheries Buybacks*. (Eds. R. Curtis, D. Squires), Blackwell Publishing, Ames, Iowa.
- Hardt, M.J. (2008) Lessons from the past: the collapse of Jamaican coral reefs. *Fish and Fisheries* **10**, 143-158.
- Hoegh-Guldberg, O., Bruno, J.F. (2010) The Impact of Climate Change on the World's Marine Ecosystems. *Science* **328**, 1523-1528.
- IUCN (2010) IUCN Red List of Threatened Species. Version 2010.4. <www.iucnredlist.org>. Downloaded on 05 December 2010.
- Johnson, A.E. (2010) Reducing bycatch in coral reef trap fisheries: escape gaps as a step towards sustainability. *Marine Ecology Progress Series* **415**, 201-209.
- Laroche, J., Ramanananarivo, N. (1995) A preliminary survey of the artisanal fishery on coral reefs of the Tulear Region (southwest Madagascar). *Coral Reefs* **14**, 193-200.
- Laroche, J., Razanoelisoa, J., Fauroux, E., Rabenevanana, M.W. (1997) The reef fisheries surrounding the south-west coastal cities of Madagascar. *Fisheries Management and Ecology* **4**, 285-299.

- Lewison, R., Crowder, L., Read, A., Freeman, S. (2004) Understanding impacts of fisheries bycatch on marine megafauna. *Trends in Ecology & Evolution* **19**, 598-604.
- Louis-Jean, L., Lenfant, P., Galzin, G., Marechal, J. (2009) Crossing fishery statistics with marine turtle bycatch data and habitat mapping in Martinique, FWI. *Proceedings of the Gulf and Caribbean Fisheries Institute* **61**, 375-379.
- Lunn, K.E., Dearden, P. (2006) Monitoring small-scale marine fisheries: An example from Thailand's Ko Chang archipelago. *Fisheries Research* **77**, 60-71.
- Mangi, S.C., Roberts, C.M. (2006) Quantifying the environmental impacts of artisanal fishing gear on Kenya's coral reef ecosystems. *Marine Pollution Bulletin* **52**, 1646-1660.
- Mangi, S.C., Roberts, C.M., Rodwell, L.D. (2007) Financial comparisons of fishing gear used in Kenya's coral reef lagoons. *Ambio* **36**, 671-676.
- McClanahan, T.R., Glaesel, H., Rubens, J., Kiambo, R. (1997) The effects of traditional fisheries management on fisheries yields and the coral-reef ecosystems of southern Kenya. *Environmental Conservation* **24**, 105-120.
- McClanahan, T.R., Mangi, S. (2000) Spillover of exploitable fishes from a marine park and its effect on the adjacent fishery. *Ecological Applications* **10**, 1792-1805.
- McClanahan, T.R., Mangi, S.C. (2004) Gear-based management of a tropical artisanal fishery based on species selectivity and capture size. *Fisheries Management and Ecology* **11**, 51-60.
- McClenachan, L., Jackson, J.B.C., Newman, M.J.H. (2006) Conservation implications of historic sea turtle nesting beach loss. *Frontiers in Ecology and the Environment* **4**, 290-296.
- Myers, R.A., Baum, J.K., Shepherd, T.D., Powers, S.P., Peterson, C.H. (2007) Cascading Effects of the Loss of Apex Predatory Sharks from a Coastal Ocean. *Science* **315**, 1846-1850.
- Ohman, M.C., Rajasuriya, A., Linden, O. (1993) Human disturbances on coral reefs in Sri Lanka - a case study. *Ambio* **22**, 474-480.
- Pandolfi, J.M., Bradbury, R.H., Sala, E., *et al.* (2003) Global trajectories of the long-term decline of coral reef ecosystems. *Science* **301**, 955-958.
- Parrish, J.D. (1982) Fishes at a Puerto Rican coral reef distribution behavior and response to passive fishing gear. *Caribbean Journal of Science* **18**, 9-20.
- Pet-Soede, C., Van Densen, W.L.T., Hiddink, J.G., Kuyl, S., Machiels, M.A.M. (2001a) Can fishermen allocate their fishing effort in space and time on the basis of their catch rates? An example from Spermonde Archipelago, SW Sulawesi, Indonesia. *Fisheries Management and Ecology* **8**, 15-36.

- Pet-Soede, C., van Densen, W.L.T., Pet, J.S., Machiels, M.A.M. (2001b) Impact of Indonesian coral reef fisheries on fish community structure and the resultant catch composition. *Fisheries Research* **51**, 35-51.
- Rosa, R.S., Mancini, P., Caldas, J.P., Graham, R.T. (2006) *Carcharhinus perezii*. In: IUCN 2010. IUCN Red List of Threatened Species. Version 2010.4. <www.iucnredlist.org>. Downloaded on 03 December 2010.
- Sandin, S.A., Smith, J.E., DeMartini, E.E., *et al.* (2008a) Baselines and degradation of coral reefs in the Northern Line Islands. *PLoS One* **3**, Article No.: e1548.
- Sandin, S.T.A., Sampayo, E.M., Vermeij, M.J.A. (2008b) Coral reef fish and benthic community structure of Bonaire and Curacao, Netherlands Antilles. *Caribbean Journal of Science* **44**, 137-144.
- Shing, C.C.A. (1995) Sharks: Overview of the fisheries in Trinidad and Tobago. *Proceedings of the Gulf and Caribbean Fisheries Institute* **47**, 318-336.
- Vidal, O., Van Waerebeek, K., Findley, L.T. (1994) Cetaceans and gillnet fisheries in Mexico, Central America and the Wider Caribbean: A preliminary review. *Report of the International Whaling Commission* **15**, 221-233.
- Ward-Paige, C.A., Mora, C., Lotze, H.K., *et al.* (2010) Large-Scale Absence of Sharks on Reefs in the Greater-Caribbean: A Footprint of Human Pressures. *Plos One* **5**, e11968.

CHAPTER 5:

Fishers, divers, and shifting baselines in artisanal coral reef fisheries:

The old men of the sea and the Pollyannas

Abstract

Coral reef ecosystems are severely degraded compared to their pristine states. Using data from interviews with 177 fishers and 211 divers on Curaçao and Bonaire, we investigate the extent to which coral reef resource users, namely fishers and professional divers, are aware of this degradation. We draw on anecdotes as well as responses to structured questions to show that fishers are more aware of the declining health of the nearshore ecosystem than divers. For fishers, awareness of degradation is independent of age and years of fishing experience – they know that the resource has declined dramatically within their lifetimes. Divers were generally less aware of declines, but older divers and divers who had been diving longer on Curaçao and Bonaire were statistically more likely to have perceived a decline. In other words, divers have a shifted baseline, whereas fishers' baselines are comparatively unshifted. As to the cause of ecosystem decline, fishers were significantly more likely than divers to blame large external factors (i.e. change in climate, change in currents, industrial fishing offshore) and divers were significantly more likely than fishers to blame fishing and coastal development. These divergent perspectives of causation have implications for management. Fishers have properly diagnosed the problem but do not generally see themselves as a cause of that problem, so they are somewhat unwilling to accept fishing restrictions. Divers have a limited understanding of the problem, but overwhelmingly support most restrictions on marine resource use. An understanding of stakeholders' conceptualizations of environmental problems is critical to designing socio-culturally palatable solutions.

Keywords: shifting baselines, artisanal fishing, SCUBA diving, coral reefs, resource degradation, resource management

Introduction

From an historical perspective, the health of the world's coral reefs has dramatically declined relative to pristine conditions (Jackson, 1997, Pandolfi et al., 2003). The degree to which an understanding of this degradation is internalized by those who use and manage coral reefs can have large policy implications. Whether we see the ocean as the same brimming cornucopia it has always been, or we never knew it had the capacity to brim, produces a different set of responses and policies than if we see the ocean's current state as but the dregs of its former self. If we believe modern fish catches and coral cover are similar to historical levels, we may be less inclined to devote effort towards conservation and restoration than if we sense the urgency of things having taken a dire turn toward a situation that may soon be irreversible. This frame of reference, or baseline, implicitly or explicitly influences resource management decisions. Baselines reflecting increasingly degraded ecological states, are termed "shifting baselines" (Pauly, 1995, Sheppard, 1995).

In this context, we explore the baseline perceptions of artisanal fishers and professional SCUBA divers (i.e. dive instructors and divemasters) as regards fish populations and, to a lesser extent, coral reef health. We employ interviews with artisanal fishers and professional SCUBA divers on Curaçao and Bonaire, two Caribbean islands of the Lesser Antilles, to identify effects of age, residence time, profession, and island on (1) expectations for ocean abundance and productivity; (2) the perceived causes of changes in fish population size; and (3) whether stakeholders (i.e. fishers and divers) with a better understanding of historical yields and populations, that is to say those with a less shifted baseline, are more supportive of fisheries management measures aimed to restore this former abundance. To our knowledge, this research

represents the only comparative study on ecological baselines of fishers and divers that has been conducted to date in the Caribbean and probably globally.

A small body of research has examined shifted baselines among fishers. Ainsworth et al. (2008) interviewed fishers in Raja Ampat, Indonesia and found that fishers with more years of experience are more likely to have noticed declines in the abundance of fish (including reef fish), marine invertebrates, and sea turtles. Bunce et al. (2008) interviewed fishers on Rodrigues island, in the south-western Indian Ocean, and found that older fishers considered a greater number of species depleted and noted earlier dates for the onset of that depletion. Sáenz-Arroyo et al. (2005) interviewed fishers in the Gulf of California and found that old fishers named five times as many species and four times as many fishing sites as depleted compared to young fishers. Lozano-Montes et al. (2008) also interviewed fishers in the Gulf of California and showed that young fishers considered fish to be more abundant now than it was in 1980, when in fact they were witnessing a very small recovery compared to historical levels. Turvey et al. (2010) interviewed fishers along the Yangtze River in China and found that younger fishers were less likely to be aware of recent megafaunal extinctions than older fishers.

The research described here augments this literature by providing the first study on fishers' baselines conducted in the Caribbean, and by comparing the perceptions of fishers with those of professional SCUBA divers.

Island histories of fishing and diving

Artisanal fishing has occurred on Curaçao and Bonaire for the last several hundred years, without any industrialized fishing or significant exportation. Dive tourism is a more recent industry, which started on Bonaire and Curaçao in the 1960s, shortly after the technology became available. Currently, tourism is the primary economic activity on both islands, more so for Bonaire where the economy is largely dependent on dive tourism (Bouchon et al., 2008),

and over 40% of tourists buy the dive tags that allow them to dive in Bonaire's waters (TCB, 2009).

Curaçao currently has a resident population of 142,180 versus 13,389 on Bonaire (CBS, 2010). Over the last 50 years, the number of fishers on both islands has declined markedly, while the number of divers has increased dramatically. We estimate the current number of fishers (both full and part-time) on Curaçao as approximately 200 (50 full-time and 150 part-time) – down from 390 in 1994 (Dilrosun, 2001) and 652 in 1959 (Zaneveld, 1961). Historical estimates are unavailable for past numbers of fishers on Bonaire, but we estimate the current number as 80 (30 full-time and 50 part-time), and assume that, similar to Curaçao, a substantial decline has occurred in the last 50 years.

The number of professional divers, around 130 on Curaçao and 120 on Bonaire, currently exceeds the number of full-time fishers on both islands by several-fold. Dive tourism did not exist fifty years ago, and grown to 35,000 visitors who traveled to Bonaire in 2009 and purchased a dive tag (TCB, 2009, E. Beukenboom, pers. comm.). Similar data for numbers of tourist divers on Curaçao was unavailable.

State of reefs and fish populations

The decline of Caribbean fish stocks has been well documented(Paddack et al., 2009)(Paddack et al., 2009)(Paddack et al., 2009)(Paddack et al., 2009)(Paddack et al., 2009)(Paddack et al., 2009)(Paddack et al., 2009)(Paddack et al., 2009)(Paddack et al., 2009), with catches that were previously dominated by large piscivorous fish now dominated by smaller, herbivorous and planktivorous species (Pandolfi et al., 2003). There are no quantitative published historical data on the extent and effects of fishing and diving on Curaçao and Bonaire despite these activities being the primary uses of the nearshore environment. Expert scientists who had extensive experience in the region described Bonaire's reefs in the early 1980s as

having “a rich reef fish population, lacking signs of over-exploitation or other serious human interference” (Wells, 1988). The same report finds “overfishing, especially illegal spearfishing, is a problem” in Curacao, which was contrasted with Bonaire where groupers, snappers, and carnivorous fish “are far more abundant.” While it is unclear whether these observations are themselves tinged by shifted baselines, the relatively lower fish abundance on Curaçao associated with relatively higher fishing pressure is empirically supported.

In 2000, mean fish assemblage biomass on these islands was quantitatively estimated as 135 g/m² based on surveys of six sites on Bonaire and five on Curaçao, with the total fish biomass and piscivore biomass higher on Bonaire than on Curaçao (Sandin et al., 2008b, M. Vermeij pers. comm.). Less than 7% of that biomass was apex predators, and no sharks were observed (Sandin et al., 2008b). Curaçao and Bonaire have higher fish biomass than unprotected areas in Jamaica, the Bahamas, Florida, or the main Hawaiian Islands, but considerably lower biomass than protected areas in Cuba (275 g/m²) and Cozumel (386 g/m²), and up to eight times lower than uninhabited islands in the Central Pacific (Newman et al., 2006, Sandin et al., 2008a, Knowlton and Jackson, 2008). Assuming the reefs of Curaçao and Bonaire have carrying capacities similar to Cuba and Cozumel, their current state implies fish biomass has been reduced at minimum by 65% compared to historical levels.

Anecdotes from interviewed fishers (Table 5.1) and some interviewed divers (Table 5.2) are aligned with this scientific assessment of reduced abundance. In variations on a theme, interviewees describe how “the coast is a desert” compared to what they witnessed earlier in their lifetimes or the stories they have heard. Photographs of spearfishers’ catches further corroborate this massive decline. Spearfishers could behave “like the reef was a supermarket,” simply choosing what they wanted, and it was common for them to catch goliath groupers almost their size (Fig. 5.1a) or a half dozen Nassau and other groupers (Fig. 5.1b) in an afternoon. Now, large groupers are rare, spearfishers’ catches are dominated by parrotfish (Fig.

5.1c), and two experienced spearfishers using SCUBA are unable to catch a single large grouper or snapper between them in two dives (Fig. 5.1d; A.E.J. pers. obs.).

In the 1950s fishers using line (both trolling and bottom fishing) in nearshore waters would catch 9 kg to 23 kg per fisher per day (also reported as 15 to 30 fish per boat per day), and that catch was dominated by large groupers and snappers (Zaneveld, 1961). In 1995, a survey was conducted of 100 fishers on Curaçao, and 75% of them reported their normal daily catch as under 5 kg per fisher (unpublished appendix to Debrot and Nagelkerken, 2000). Data collected by the Fisheries Department on Curaçao bolster such claims, with data that boats under 10m length (which is the majority of boats) had a mean catch of 9.5 kg per day in 2001 (Dilrosun, 2001). With normally two fishers per boat, this was a mean the catch per day per fisher of 4.75 kg – well beneath the low end of the range for the 1950s.

For trends in coral cover there is more consistent long-term scientific data available. Curaçao and Bonaire are oceanic (as opposed to continental shelf) islands with similar reef profiles: a terrace that extends 50-100 m from shore, followed by a dropoff starting at 8-12 m, and then a steep slope to 50-60 m where there is a plateau (Wells, 1988). Mean coral cover as of 2000 was estimated at ~25% for sites on Curaçao and Bonaire combined, with no significant differences between the islands (Sandin et al., 2008b, S. Sandin pers. comm.). This is substantially greater than the Caribbean-wide mean of 10% cover (Gardner et al., 2003). However, data from permanent photoquadrats at three sites on Curaçao and one site on Bonaire show that coral cover on the shallow reefs (10 m to 20 m depth) declined approximately 45% between 1973 and 2003, although cover did not change significantly on the deep (30m to 40m depth) reefs (Bak et al., 2005). Another recent study found that coral cover on Bonaire declined by approximately 50% from the early 1980s to 2008 (Stokes et al., 2010). These declines are less extreme than the 80% decline in coral cover from the mid-1970s to 2000 for the entire

Caribbean region (Gardner et al., 2003), but Curaçao and Bonaire can be thought of as on the same trajectory of degradation merely a decade or so behind (Sandin et al., 2008b).

Methods

From August through December 2009 in Curaçao, and in April and May 2010 in Bonaire, A.E.J. interviewed 177 full-time and part-time fishers and 211 professional SCUBA divers, including dive instructors, divemasters, and dive guides. The lack of comprehensive lists of the fishers and divers on these islands precluded stratified random sampling. Consequently, every effort was made to include fishers at every port and divers at every shop, to interview fishers and divers of all ages, and to conduct as many interviews as possible.

Interview methodology

Fishers and divers were approached, the research project was explained, and interviews were conducted immediately or an appointment was made for a future time. All interviews were conducted in person by A.E.J., with an English-Papiamentu-Dutch translator available for all fisher interviews. A translator was not used for the diver interviews as they all spoke fluent or nearly fluent English. At the end of each interview, contact information for additional fishers and divers was requested, in what is termed a snowball sampling strategy (Bernard, 1994). Each fisher survey contained 255 questions, and each diver survey contained 125 questions. Surveys included questions on a variety of topics including fishing and diving practices, income, and marine resource management. A subset of the data focused on fisher and diver perceptions of reef resources (see Appendix A for question list) are presented here. Fishers were asked about what they catch and divers were asked about what they see underwater. Where these questions were parallel, fisher and diver responses are directly compared. A selection of anecdotes offered by interviewees in elaborated responses to survey questions is also presented.

The survey solicited participants' opinions of a variety of regulatory measures (Appendix B). Questions focused on fishing gear restrictions (i.e. requiring modifications to certain types of fishing gear or banning gear types all together) and area restrictions (i.e. temporary or permanent no fishing or no diving reserves). Using the nine gear questions and seven reserve questions, "gear scores" and "reserves scores" were calculated for each interviewee based on the percentage of gear restrictions and area restrictions they supported. The highest possible score is 100 (indicating that all responses favored restricting resource use) and the lowest is zero (indicating opposition to all mentioned restrictions). Using responses to gear and reserve questions and five additional miscellaneous management questions (i.e. limiting the number of fishers and divers, banning anchoring, banning the catch of juveniles, and banning catch of particular fish species), we calculated an overall "conservation score" for each individual.

We also created a "baseline score" using the responses to the questions used to identify interviewees' ecological baselines. For each question, points were awarded based on the level of awareness of ecosystem degradation that the responses implied. For example, a fisher's response that he catches smaller fish than previous generations of fishers did would earn one point, whereas a response that fish size is the same would earn 0.5 and a response that fish size is bigger would earn zero points. The maximum and minimum possible scores were 7 and zero respectively.

Data analysis

In order to probe the existence of a shifting baseline phenomenon, fishers and divers were categorized by age groups: young (15 to 30 years of age), middle (31 to 45), old (46 to 60), and older (61 to 81 years). Altering these age group definitions by a few years in either direction did not change patterns of the results. Since there are so few professional divers

over 60, old and older groups of divers were combined for analysis. Divers were also categorized based on years of diving experience on their respective islands, here termed residence time (<1 year, 1 to 4 years, 5 to 10 years, and >10 years), and by total years of diving experience (<10 years, 10 to 19 years, and ≥ 20 years). Fishers were categorized by years of experience (<10 years, 10 to 19 years, 20 to 29 years, 30 to 39 years, and >40 years).

We compared survey responses between islands and professions, and among age groups and residence times. For categorical response variables, comparisons were made using χ^2 goodness-of fit-tests, and where sample sizes were small using Fisher's exact tests. For continuous response variables (i.e. demographic data and best/worst year of fishing), comparisons were made using one-way analyses of variance (ANOVA) with Bonferroni corrections for multiple comparisons. For biggest fish data, fish length and mass were regressed on catch year. All reported errors are standard errors.

Results

Fisher and diver demographics

The 388 fisher and diver interviews involved an estimated 63% of fishers on Curaçao, 65% of fishers on Bonaire, 86% of professional divers on Curaçao, and 83% of professional divers on Bonaire (Table 5.3). There were significant demographic differences between professions and islands. Fishers ranged in age from 15 to 81 years with a mean of 49.2 (SE = 1.15), and divers' ages ranged from 18 to 67 with a mean of 36.8 (SE = 0.76). Divers were significantly younger than fishers overall and on each island (all $p < 0.0001$). The age distributions of fishers on Curaçao and Bonaire were not significantly different from each other. Divers on Bonaire had a mean age of 39.7 (SE = 1.23), significantly older than the mean of 34.3 (SE = 0.87) for divers on Curaçao ($p < 0.0001$).

Fishers had 3 to 70 years of fishing experience. Divers had 1 to 54 years of experience overall, with as few as two weeks of diving on Curaçao or Bonaire in particular (i.e. residence time). On both islands, fishers started fishing at an earlier age and in an earlier year than divers started diving, and thus have more years of experience (all $p < 0.0001$). Fishers began to fish at a mean age of 12.6 (SE = 0.54), and divers to dive at a mean age of 22.2 (SE = 0.57). Fishers on Bonaire have a mean 40.8 (SE = 2.61) years of fishing experience, significantly more than the mean of 34.6 (SE = 1.21) for Curaçao ($p = 0.001$). Divers on Bonaire have a mean of 17.0 (SE = 1.12) years of diving experience overall, significantly more than the mean of 12.4 (SE = 0.82) for Curaçao ($p = 0.015$). Divers on Bonaire had a mean residence time of 10.1 years (SE = 0.95), significantly more than the mean of 7.1 years (SE = 0.09) for divers on Curaçao ($p = 0.002$). Fishers fish a mean of 3.6 days per week (SE = 0.15), without significant differences between islands or age groups. Divers dive a mean 8.0 times per week (SE = 0.33), without significant differences between age groups, although divers on Curaçao dive significantly more frequently than their counterparts on Bonaire ($p = 0.007$).

Fishers' families have been fishing for a mean of 3.1 generations (SE = 0.11), significantly more than the mean of 1.3 (SE = 0.04) for divers ($p < 0.0001$), a trend that holds for each island individually (both $p < 0.0001$). First generation divers comprised 69% of those interviewed, compared to only 18% of fishers who had no family history of fishing. Number of generations did not differ significantly between islands for either fishers or divers.

Current fish catches/populations

When asked whether they catch more or less fish than previous generations, the large majority (89%) of fishers responded that they catch fewer fish, with no significant differences in responses between islands, age groups, or years of experience (Graph 5.1a). Most fishers who responded that their catches were greater added caveats such as noting that they now have larger

boats, go further offshore, and/or have more advanced gear (e.g. fish finders). Of the six fishers who responded that they catch the same amount of fish as previous generations, two explained that they were able to do so only because of better equipment and high effort. Four fishers remarked that they catch less despite using better equipment.

The majority of divers (77%) consider the local fish populations to be average or more abundant than average compared to what they believe a coral reef fish population should look like (Graph 5.1b). There was no significant effect of age group or residence time on diver responses. On Curaçao, divers with 20 or more years of diving experience were more likely to consider fish populations depleted than were divers with fewer years of experience ($p = 0.083$). Divers on Bonaire rated their fish populations as more abundant than did divers on Curaçao ($p < 0.0001$).

Best and worst catch years

Fishers were asked the year in which they had the best catches of their lives and the year in which they had the worst. The mean best year was 1998 (SE 1.0), which was not significantly different between islands, but did differ according to age groups and years of experience (Graph 5.2a). Young fishers and less experienced fishers were significantly more likely to report recent years as their best (both $p < 0.0001$). The mean worst year was 2009 (SE = 0.16), which did not differ between age groups (Graph 5.2b). The most frequently reported worst year was the year the interview took place, which was 2009 for Curaçao and 2010 for Bonaire.

Graph 5.2c displays the relationship for each fisher between their best year of fishing and the year they started to fish. The line that describes that mean relationship has a slope of 0.31 (SE = 0.06), which is not significantly different from a slope of 0.25 that would describe a random relationship between the best year and start year of fishing. Graph 5.2d displays the

median best fishing year that corresponds with each fishing start year. That relationship has a slope of 0.027 (SE = 0.05), also not significantly different from random.

Fish catch/population change in last 5 years

Interviewees with more than five years of experience on Curaçao or Bonaire were asked to compare either current fish catch (for fishers) or current fish population size (for divers) to that of five years ago (Graph 5.3). Fishers were more likely than divers to perceive a decrease – 65.1% of fishers versus 40.3% of divers ($p < 0.0001$). Younger and less experienced fishers were significantly less likely to perceive declines in the fish population (both $p < 0.003$). No fishers on Bonaire, and only 7% fishers on Curaçao, perceived an increase in catch. Just as for the question about catches now compare to those of previous generations, four of the 21 fishers responded that they catch the same amount of fish as they did five years ago added the caveat that they are only able to maintain their levels of catch because they are now using better equipment. Two fishers remarked that their catches have declined despite better equipment.

Older divers and divers with more years of experience were more likely to perceive a decrease in fish populations (both $p < 0.02$). On Curaçao, those with a residence time over 10 years were more likely than more recently arrived divers to have perceived a decrease in fish population ($p = 0.025$). No diver on either island with a residence time over 20 years believes the fish population has increased in recent years ($N = 27$).

Fish catch/population change in last 10 years

When fishers with ten or more years of fishing experience ($N = 167$) were asked how catch has changed in the last ten years, 66% responded that catch was much worse and an additional 21% responded that catch was worse, with no significant differences in response distributions between islands or age groups (Graph 5.1e). Of the four fishers who responded that

their catch is either better or much better than it was 10 years ago, two noted this was due to better equipment and one noted this was due to increased fishing effort. Three fishers remarked that their catches in the last 10 years have declined despite better equipment.

This same survey question was asked of 100 fishers on Curaçao in 1995 (Debrot and Nagelkerken, 2000). In the 14 years from that survey to this one, opinion seems to have shifted towards a greater proportion of fishers, nearly 20% more, thinking fishing has gotten “much worse” (Graph 5.4).

Both fishers and divers were asked whether they think there are fewer fish in the ocean now compared to ten years ago, and 89% of fishers and 81% of divers responded affirmatively. Divers were significantly more likely than fishers to respond equivocally ($p = 0.001$). Diver responses were not significantly different between islands or across age groups or residence times, but those with more years of experience were more likely believe fish populations have declined in the last decade ($p = 0.031$).

Change in fish size

When asked whether they catch bigger or smaller fish than previous generations, the majority of fishers responded that they catch smaller fish (Graph 5.1c), with no effect of island, age group, or years of experience. Of the ten fishers who responded that they catch bigger fish than previous generations, two added the caveat that it is due to having better equipment. Five fishers remarked that they catch smaller fish despite using better equipment.

This perception of declining fish size is supported by fishers' responses about the size and year they caught the biggest fish of their life. There is a significant negative correlation between catch year and the length and mass of the largest fish caught (both $p < 0.03$). This relationship holds, when the data are disaggregated by gear type, for the length and mass of fish

caught with line (both $p > 0.001$, $N = 117$), the length but not mass of fish caught with trolling ($p = 0.018$, $N = 58$), and the length but not mass of speared fish ($p = 0.68$, $N = 38$, Graph 5.5).

While there was no formal question in the diver survey inquiring about a change in the size of observed fish, many divers volunteered anecdotes to that effect in response to the questions of how fish populations have changed in the last five years and which species they now see less often. Forty-four percent of divers noted the absence or decline of large fish, with significantly more divers on Bonaire (58%) remarking on this than divers on Curaçao (31%, $p < 0.0001$). On both islands, divers with more years of experience were more likely to mention this size decline ($p < 0.0001$). On Bonaire, but not Curaçao, divers who were older or had a longer residence time were significantly more likely to note the lack of large fish (both $p < 0.01$).

Coral health

The large majority of divers (81%) perceive the reefs on their respective islands to be in average or better than average health compared to what they think a coral reef should look like, with only 3% of divers considering the reefs very unhealthy (Graph 5.1d). The distribution of responses did not differ significantly between islands or with years of experience. On Bonaire, older divers and those with a longer residence time were more likely to consider the reef unhealthy or very unhealthy (both $p < 0.05$). When divers with a five year or longer residence time ($N = 114$) were asked how reef health has changed in the last five years, 81% responded that reef health is worse or much worse compared to five years prior (Graph 5.1f). On Bonaire, older divers, divers with longer residence time, and divers with more years of experience were more likely to note that reef health had become much worse (all $p < 0.05$). This question about reef health was not asked of fishers as most of them snorkel or dive too infrequently to have first-hand knowledge of coral status and trends.

Site abandonment

Forty-eight percent of fishers and 57% of divers (significantly more divers ($p = 0.072$)), report that they have stopped fishing or diving in some locations because the reefs or fish populations are no longer healthy there. There were no significant effects of age or years of experience for fishers. Some fishers explain that the reason they have not abandoned sites is that there is nowhere else to go, or their boats are not large enough to take them to where there are still fish. Divers on Bonaire were significantly more likely than divers on Curaçao to have abandoned dive sites due to reef degradation ($p < 0.0001$), with many citing the effects of a recent storm. On Curaçao, likelihood of dive site abandonment increased with residence time and years of experience (both $p < 0.05$). These relationships did not hold on Bonaire. Some divers note that the reason they have not abandoned sites is that the dive shops where they work require them to continue diving at sites they would otherwise have abandoned.

Formerly caught/seen species

Interviewees were asked whether there are some species they used to catch or see that they now no longer or very rarely see. This question was a late addition to the survey so it was only posed to fishers and divers on Bonaire, not on Curaçao. Ninety-six percent of fishers and 94% divers with over five years of residence time reported the loss of some species (Table 5.4), with no significant effect of age group or years of experience for fishers. Older divers and divers with more years of experience were more likely than younger divers to note the absence of species (both $p < 0.02$). The reef fish species most commonly mentioned by fishers as now absent from catches were coneys (*Epinephelus fulvus*), Nassau groupers (*Epinephelus striatus*), and yellowtail snappers (*Ocyurus chrysurus*). The taxa most commonly mentioned by divers as now rarely observed were groupers (unspecified species), green moray eels (*Gymnothorax funebris*), lobster (*Panulirus argus*), and barracuda (*Sphyraena barracuda*). Both groups

mentioned yellowtail snappers, groupers generally, and Nassau groupers in particular as having experienced severe declines.

Causes of fish population decline

Both fishers and divers were asked what they believe has caused the declines in fish populations that they perceived. Answer choices, not mutually exclusive, were: pollution, too much fishing, climate change, SCUBA diving, change in currents, will of God, small mesh nets, spearfishing, and coastal development. Fisher and diver responses differed significantly for every one of the causes (Graph 5.6). Fishers were significantly more likely than divers to blame change in climate, change in currents, SCUBA diving, and the will of God (all $p < 0.03$), with no effects of residence time or years of experience. Divers were significantly more likely than fishers to blame pollution, overfishing, small mesh nets, spearfishing, and coastal development (all $p < 0.04$). Divers on Bonaire were more likely to blame SCUBA diving than their counterparts on Curaçao ($p = 0.004$). Divers on Curaçao were more likely than those on Bonaire to blame pollution, nets, and spearfishing (all $p < 0.04$). Older divers were more likely to mention the will of God as a factor ($p = 0.011$). Younger divers were more likely to blame coastal development ($p = 0.005$).

Interviewees were asked whether there were additional causes that have contributed to fish declines. Industrial fishing offshore by foreign vessels was the most common response for both fishers and divers, with long-lining and large nets as the gear types most frequently mentioned by name. Fishers also mentioned use of sunscreen by tourists and overfishing of baitfish. Divers on Bonaire mentioned the lack of sewage treatment and cruise ships as additional factors contributing to fish declines.

This question about causes of fish population declines was also posed to fishers on Curaçao in 1995 (Debrot and Nagelkerken, 2000 and associated unpublished appendix).

Comparing the results of the five causes that were mentioned in both that study and the present one indicates a shift in opinions over time (Graph 5.7). Fishers seem to have become less concerned with small-mesh nets, spearfishing, and overfishing, and more concerned with industrial fishing and SCUBA diving. Industrial fishing was an additional cause volunteered by interviewees in both surveys (as opposed to a listed option) so those results can be directly compared.

Additionally, fishers in the present study were directly asked if their fishing reduces the number of fish that will be in the ocean next year. Only 11% of fishers responded that, yes, their fishing is a cause of the declining the number of fish.

Support for Management

The mean gear scores, reserve scores, and conservation scores were all significantly higher for divers than for fishers (all $p < 0.0001$, Table 5.5). For fishers, there was a positive correlation between gear score and baseline score ($p < 0.05$). There were no other significant correlations between management scores and baseline scores for fishers or divers.

Discussion

The coral reef ecosystems of Curaçao and Bonaire are in better condition than many other places in the Caribbean. That said, their current state is but a shadow of their former abundance and productivity. Relatively low human population size and low fishing pressure (including no export and a negligible aquarium trade), and infrequent use of destructive gears such as dynamite have delayed the degradation of these islands' reefs. However, the lack of strong fishing, diving and development regulations are now having undeniable and often quite dramatic effects. While both fishers and professional divers spend much of their time on or

under the water, they have vastly different perceptions of the state of the nearshore ecosystem, how that state has changed, and what has caused those changes.

The Old Men and the Pollyannas

Overall, fishers perceive a much larger decline in fish populations than divers, whether this is measured as change in catch in the last five years, the number of fish in the ocean now compared to ten years ago, or species they no longer catch or see. Fishers of all ages notice that they are catching fewer and smaller fish, and that even compared to just ten years ago catch is much worse. These results are similar to those of a 2006 survey of 52 fishers on Curaçao in which 100% of participants remarked that the length, weight, and quantity of the fish they catch has declined (Schultink and Lindenberg, 2006). Similar to the 96% in this study, 90% of fishers in the previous study stated that there are species they now rarely or never catch, with groupers and snappers most frequently mentioned.

There was one exception to the lack of relationship between fishers' ages, their years of experience and their survey responses. For the question of how catches have changed in the last five years, younger fishers were less likely to respond that there has been a decrease. This is inconsistent with fisher responses to other questions, and it is unclear why this one would be so different; although it should be noted that those younger fishers were not asserting that there has been an increase, but that there has not been a change at all.

While fishers have a reputation for exaggerating the sizes of the fish they have caught, it is unlikely that they do so in direct proportion to the year in which they caught the fish. A fisher who reported catching his largest fish within the last few years was more likely to report a smaller specimen than a fisher who caught his largest fish decades ago. Fishers also often voluntarily retrieved photographs to illustrate the big fish stories they told.

The anecdotes illustrate, fish are getting harder to catch, it is harder to make a living as a fisher, and fishers of all age groups and years of experience are aware of this. Fishers' responses to the question of when they had their best year of fishing provides some evidence that fishers' baselines have shifted (Graph 5.3d). The relationship between the best year of fishing and the start year is not significantly different from random. This lack of relationship could be due to the specific wording of the question, which asked about the year in which they had the best catch of the lives, defined as the catch with the greatest market value, not the year in which year they caught the most fish overall. Fishers who have had several catches of equally grand magnitude in their lives, or have not accounted for inflation, may have mentioned more recent years even if those were not truly their best. In counterpoint, fishers always mentioned recent years as their worst.

The 1995 survey concluded that fishers had “all but written-off demersal/reef fishing along the southwest coast and feel that a total collapse has taken place in the last decade” (Debrot and Nagelkerken, 2000). Of the fishers in that study who reported having increased their fishing effort, 45% gave declining catches as their reason. Given this scenario, it is not surprising that the number of fishers on these islands has rapidly declined. It is simply no longer profitable, and only a handful of young individuals are planning to pursue careers in fishing.

In general, divers have a much rosier view than fishers of the state of the reefs and of fish population health. There are many potential explanations for this. This is perhaps because, despite questions phrased to elicit responses that compared Curaçao and Bonaire to what they thought a healthy reef should look like, divers were actually evaluating these islands on the scale of the modern Caribbean, or compared to other places they have been diving. Or perhaps divers are naïve, or they believe the tourist board and dive magazine hyperbole, or their answers are financially motivated by the need to sustain the good reputations of Curaçao and Bonaire as

premier dive destinations. The extent to which these potential explanations apply cannot be identified with these survey data.

The exception to divers' optimistic view is their perception of fish size. Although there was no direct question about a change in fish size, almost half of interviewed divers mentioned the lack of large fish. This perspective is supported by research that notes the piscivores on these islands are predominantly small-bodied (Sandin et al., 2008b). Divers seem to be better attuned to the lack of large fish than they are to more general ecosystem health.

Explaining differences in perception

The differing perceptions of fishers and divers can be explained in large part by differences in the demographics of these two groups. On average, fishers are older than divers, have more years of experience, have more generations of their family who have worked in the profession, and have been on the islands longer. SCUBA diving has existed for a brief time compared to the history of fishing. The average fisher has been fishing on Curaçao or Bonaire more than four times longer than the average diver has been diving on these islands. Fishers have on average three or four generations of fishers in their families – basically, as far back as they know, their families have been fishing; whereas most divers are the first generation. As a result of these factors, there is likely less intergenerational knowledge transfer for divers – they may not be hearing stories and seeing photos of the glory days, which could be contributing to a shifted baseline. This is in contrast with fishers who quite frequently during interviews retrieved old photos of themselves with large fish to corroborate their stories.

In addition to differences between fishers and divers, there was interesting variation within divers as a group. First, divers on Bonaire were more likely than divers on Curaçao to consider the fish populations depleted, to notice a lack of large fish, and to have abandoned some dive sites. Perhaps divers on Bonaire are more likely to perceive these changes because

reef ecosystem degradation is slightly lagged there relative to Curaçao, and large fish have declined there more recently. This lag could be the effect of better enforcement of the spearfishing ban and smaller human population size, and therefore lower fishing and pollution pressures. There is evidence for the relationship between human population size and abundance of predatory fish in the Caribbean (Stallings, 2009). Regardless of the causes, such a lag would render divers on Bonaire more likely to have actually witnessed the decline. This inter-island difference in perception has scientific support (Sandin et al., 2008b, S. Sandin pers. comm). One can still regularly see tiger groupers (*Mycteroperca tigris*) on Bonaire, but they are effectively absent on the shallow reefs of Curaçao (A.E.J., pers. obs.)

Second, divers who are younger, have shorter residence times, and have fewer years of diving experience are less likely to consider the coral reefs degraded and declining. This reflects a shifted baseline. The lack of independence of these variables only buttresses the result. This is most visually striking in Graph 5.4, which clearly shows the effect of age on perception of fish populations.

In general, fishers consider fish populations to be in a much more dire state than divers do. Perception is a function of experience. It has been possible for currently active fishers and divers to witness firsthand the declines in coral reef ecosystems over the last few decades. But the lack of tradition and years of experience may be preventing divers from appreciating these changes to the same extent.

Fishers may have a deeper understanding of resource degradation than divers in part due to the directness of the financial relationship between fish stocks and fisher incomes. In contrast, divers' incomes are somewhat decoupled from reef health. The number of dive tourists and the number of dive shops continues to increase even as the health of the reefs declines. Recreational divers, especially the inexperienced, are usually excited to simply see a reef regardless of how different it is from its historical state. If a dive instructor is not able to show

clients as many large fish there may be a longer-term effect on his or her income, but if a fisher is unable to catch a fish, that financial effect is immediate.

Comparison with previous research

To our knowledge this represents the first attempt anywhere in the world to identify shifting baselines among SCUBA divers. However, our fisher survey results are directly comparable to interviews with Indonesian fishers (Ainsworth et al., 2008). Unlike that study, we do not find a consistent and negative relationship between perception of changes in abundance and years of fishing experience. However, we also do not, as they do, ask about trends for specific taxa, so it is unclear how the responses of fishers on Curaçao and Bonaire would compare. Our results seem to contradict those of Bunce et al. (2008) and Sáenz-Arroyo et al. (2005), as those studies identify a strongly shifted baseline amongst fishers and we do not. However, we cannot make a direct comparison because we did not ask questions about depletion trends at the species level. Fishers on Curaçao and Bonaire may have relatively unshifted baselines as regards the general trend of fish population declines, but have age or experience-based differences as regards knowledge of more specific changes. One example of this could be a lack of understanding of the former abundance of groupers and the timeline of their decline.

These comparisons raise the issue of the level of resolution at which a shifted baseline is cause for concern. Is it enough that fishers on Curaçao and Bonaire are all equally concerned about the decline in fish populations? Or must fishers of all ages and years of experience have the same perception of when that decline started and which species have been most affected? If shifting baselines are a concern because of the implication that they result in inadequately stringent management, then perhaps an understanding of the details of the decline are less important than a general stakeholder awareness and an accurate perception of the causes of the

decline. Fisheries managers, however, should make every effort to maintain an unshifted and detailed understanding of the pristine ecological composition of the systems they manage. To this end, they can draw on the knowledge of older, more experienced fishers (Johannes et al., 2000).

It is also important to note that many of these observed or perceived changes over the last 50 years may be marginal compared to the dramatic ecosystem changes that have occurred on coral reefs over human history, especially with regard to the extinction of megavertebrates such as monk seals (Pandolfi et al., 2003, Pinnegar and Engelhard, 2008, Jackson, 1997, Jackson et al., 2001, Jackson, 2001)

Perceived causes of declines

The differences in perception of fish population trends between fishers and divers are accompanied by equally great differences in the perceived causes of these trends. Fishers tend to blame large-scale factors such as changes in climate and currents and industrial fishing, while divers blame local factors. Basically, fishers repudiate blame and affix it to something out of their control, while divers blame fishing. Considering how concerned divers are with overfishing, it is somewhat surprising that they are not more pessimistic about the state of the fish populations. This can be interpreted as denial on the part of both groups. Fishers are in denial that fishing has reduced the number of fish – only 11% believe that their fishing has contributed to the declines they see. Comparison with the 1995 survey data show this denial has been increasing. Divers are in denial about how degraded the ecosystem is – even though they are aware that predators are missing from the reef they still consider the reefs to be healthy and the fish to be abundant. Divers seem to believe they are still in paradise.

Baselines and reef management

These baseline perceptions have policy implications. One might think that those who are more aware of declining ecosystem health would be more inclined to support measures to improve ecosystem health. In fact, the opposite is true here. Fishers are more cognizant of the declines, but are also less supportive of restrictions. This may partly be a result of fishers not wanting their own behavior restricted, or more generally due to a dislike of authority, but two other explanations deserve consideration.

First, fishers may be less receptive to implementation of fishing regulations as part of the solution if they do not believe that fishing caused the problem. Because fishers attribute fish declines mostly to factors out of their control, to them restrictions on their behavior could feel like scapegoating. This exemplifies why an understanding of stakeholder conceptualizations of the problem is critical to designing socially and politically palatable management solutions.

Second, while fishers may be more acutely aware of declining resources they may also have fewer options for alternative employment and have strong cultural ties to fishing. This could result in unwillingness to have their fishing activities constrained in the short term even if they could envision the long-term benefits of such measure. Perhaps this is a situation where the establishment of property rights could serve to simultaneously protect fish populations and fishers' incomes by controlling effort while providing access.

Another policy option is to take advantage of the fact that the average age of interviewed fishers, despite concerted efforts to survey all ages, was almost 50 years. Why are most of the fishers old? Why is the number of fishers declining? Because "it's not like it used to be." There used to be more fishers because there used to be more fish, and those who are still fishing know that it is the end of an era. This presents an opportunity to establish limits on future fishing effort. A combination of grandfathering in current fishers, thereby avoiding some of the social resistance, and restricting new fishers could be effective.

The fact that these fishers have relatively unshifted baselines makes the Sisyphean task of sustainable coral reef fisheries management slightly more trackable. The positive correlation between baseline score and gear score implies that raising awareness about historical ecosystem baselines could increase support for fisheries management. The apparent lack of causal link for fishers between overfishing and depleted fish populations, however, is a concern, and efforts should be made to increase awareness about the effects of fishing. Efforts should also be made to counteract the shifted baselines of divers, by encouraging knowledge transfer from those with more experience. These are important steps towards conservation in that they promote a longer-term perspective, re-calibrate expectations of ecosystem abundance and productivity, and facilitate development of appropriately high management goals. Establishing no-take marine reserves is another means of combating shifting baselines (Bohnsack, 2003, Knowlton and Jackson, 2008), as they can help restore areas and thereby crack open a window into the past.

Acknowledgements

Above all, I thank the fishers and divers who generously shared their time and knowledge with me. This research would have been impossible without the assistance of wonderful translators K. Brown, M. Brown, J. Vollenbregt, D. Abraham, C. Dovale, H. Liber, and M. Chirino. F. Dilrosun of Curaçao's Dienst Landbouw, Veeteelt & Visserij, and R. de León and E. Beukenboom of Stichting Nationale Parken Bonaire provided generous logistical support. S. Sandin, T. Groves, L. Levin, and M. Lauer provided valuable comments on earlier drafts. Funding was provided by NSF Graduate Research, Switzer Foundation, and AAUW fellowships, and Scripps Institution of Oceanography.

Chapter 5, in full, is currently being prepared for submission for publication of the material. Johnson, Ayana Elizabeth; Jackson, Jeremy B.C. The dissertation author was the primary investigator and author of this material.

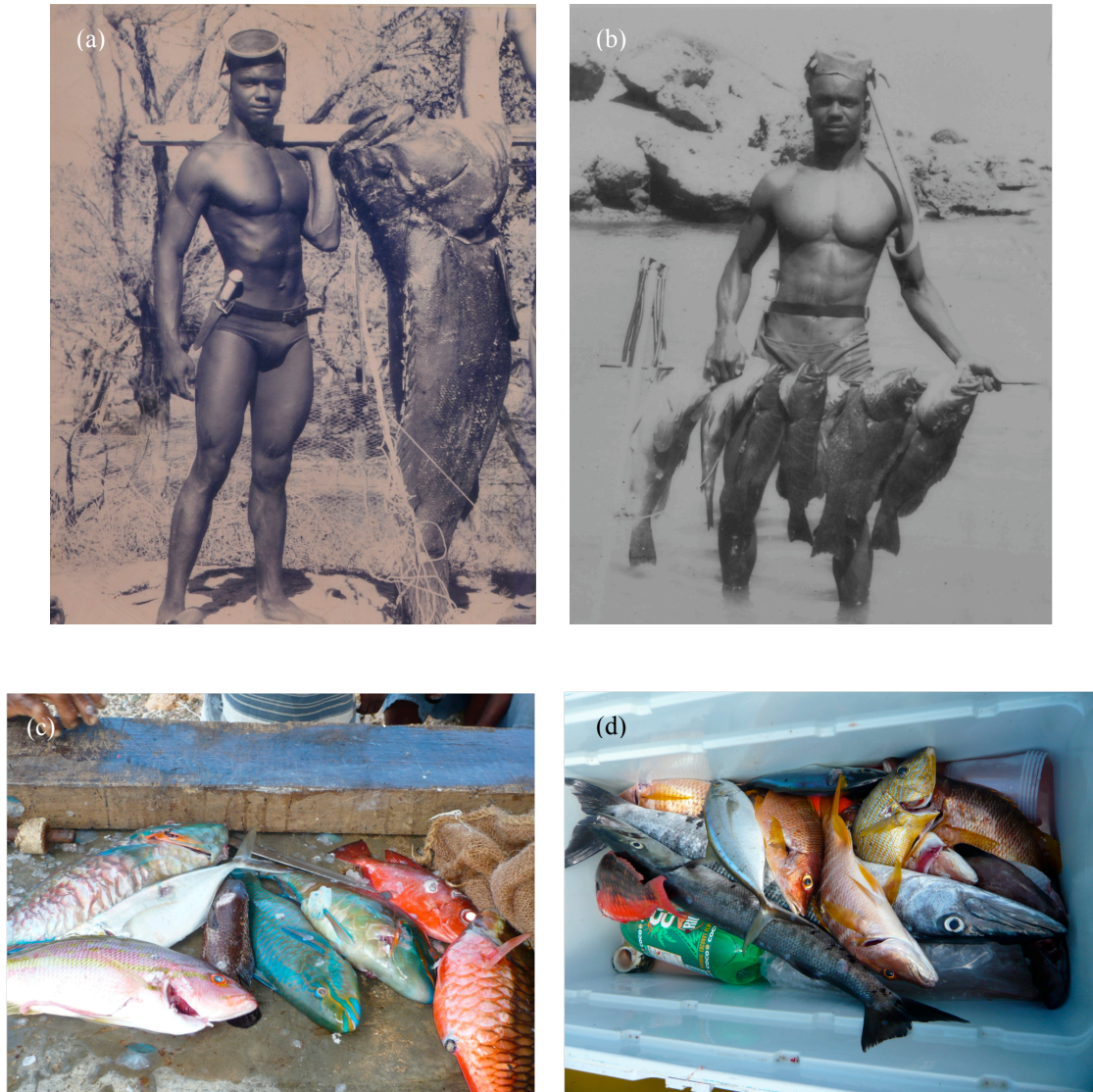


Figure 5.1. Catch of spearfishers in Curaçao in 1960, (a) a goliath grouper and (b) Nassau and other groupers; and (c) a day's catch for one fisher using snorkel (mostly parrotfish) and (d) for two fishers using SCUBA in 2009.

Table 5.1. Fisher anecdotes offered in response to interview questions (see Appendix A for question list).

	Age	Anecdotes
young	15	Now we show fish size horizontally [holds hands out to sides] instead of vertically [holds hand at a height off the ground].
	19	I hear that right past the dock you could catch fish. Now you have to go far, to the north shore.
	22	Fishing might be profitable for 15 more years. Because if you see 15 years ago and now, and then add 15 years it goes to zero.... Actually, compared to 15 years ago it <i>is</i> zero.
	27	In 1994 I could catch 30lbs of purunchi [grasby] after school. Now it takes 3 whole days to catch that much.
	29	You could just anchor outside of Harbour Village and catch 100kg of rainbow runner. Now you have to go much further away
middle	33	I'm one of the best fishermen in the club. I catch a lot of fish, but my name is not on that plaque because I don't catch big fish. All the records were set in the 1970s.
	40	Compared to previous generations?!?! I used to catch more when I had worse gear and worse technique! And you used to be able to catch fish from the rocks, now there is nothing left on the shallow reefs in general.
	41	In this world there is no fish left. Some people go out the whole day and catch nothing. So I want my kids to go to school and learn more.
	43	It's not the same as it used to be. The income is a lot less. Now need to use nets and spears if fish don't bite.
	43	The fish are small. They are babies. If fishing was profitable, more boats would go. There is no 401K plan, there is no inheritance, I'm just trying to survive.
	45	Sometimes I go from Curaçao to Bonaire and still don't catch anything.
	46	I haven't seen a Nassau grouper in 10 years. And there used to be a lot of nurse sharks. My wife is starting to work and I am working more on land because I can't make money fishing. There are no more big fish.
old	49	Now if you catch 2 or 3 tuna that's good. You used to catch 10 to 12 every time.
	49	There is nothing left. The sea is bad. If I go fishing with boat and catch nothing, then I go with snorkel.
	49	We as spearfishers made the Nassau grouper disappear. And strawberry grouper and tiger groupers too. I was one of the destroyers. I am going to hell.
	50	I can't even break even. Since 1999 catch is very bad. I just finished fishing and now I have to go to McDonald's to get food because I didn't catch anything.
	53	30 years ago at Westpunt I would get 30kg tunas. I would get so many fish I would fill up my boat and I'd have to stop.
	55	Before fishing was profitable, but now? No. Or you have to use nets like the Chinese do.
	56	Ten years ago 25kg was a big wahoo, now people say 15kg is big.
	57	The fish he brings home are so small compared to the past (says fisher's wife)
	57	In 1970 - 1973 we used to charter planes and send 100lbs of Nassau grouper to the Intercontinental in Curaçao [from Bonaire]
	60	Previous generations were choosing the fish. You could go with a speargun and just chose what you wanted for dinner like the reef was a supermarket.
	60	You used to be able to catch queen snapper at 30m, now there are none until 100m.
	60	Malissimo! Hodidu! The fish is gone!

Table 5.1 continued.

	Age	Anecdotes
	62	The coast is a desert now.
	64	A lot of people have stopped fishing because catch is bad. You used to at least catch something everyday, now many days you catch nothing. Now even when diving you don't see big fish anymore.
	67	If I were younger and could choose to work on land, I would. Now I throw back Spanish hogfish when I catch them because they are so rare. With a small boat you can't catch anything. Day by day it's getting less.
	67	In 1970 they used to be all over. I could catch 10 in a day. When I moved here people would tell me they saw a jew fish and I would go get it. I'm very guilty of extinguishing them. We didn't know you could do that – there were so many.
older	74	I used to catch big fish right in front of the harbor. Now you can go all the way to Venezuela and back and catch nothing. It started to go down after 1987. Before that every day was 80kg, 120kg on the north shore. 10, 20, 30 dorado a day <i>and</i> 10 tuna. Now the fish are smaller – especially the tunas. I sold my boat because I can't break even anymore.
	75	We caught so many fish here on Bonaire we couldn't sell it all. We would have to go to Curaçao to sell it. But now there are so many people and restaurants.
	75	Yellowfin tuna used to be so common you couldn't sell it.
	78	Now there is nada nada.
	81	Thirty years ago there were a lot of fish, now there are no more fish. We used to catch lots of kingfish, now you only see them in pictures.
	81	I look... look... look Nothing.

Table 5.2. Diver anecdotes offered in response to interview questions (see Appendix A for question list).

	Age	Anecdotes
young	19	If I had to guess I would say there are more fish than there were ten years ago because fish multiply very quickly.
	22	Compared to what used to be here, but still top notch compared to elsewhere
	23	Here we mostly have the small stuff without much meat so people don't fish much.
	26	It's almost becoming like Jamaica, with no fish.
	27	I have seen old photos of Bonaire. It has gone down a lot since then.
middle	36	I no longer see large turtles, there are way less rays, octopus and sea horses. I probably like those so much because I hardly ever see them.
	38	It's a young reef with a lot of potential, but it's also very fragile.
	38	There is tremendous pressure on the reefs here, but they are good compared to other places.
	41	I don't want to make it sound like it's bad here, but when I started in 1992 the corals came close to the shore.
	42	Nine years of diving here and I have never seen a shark.
	44	The reefs are very healthy. It's still astonishing every time I get in the water.
	44	I miss the big fish. Some places it's like diving in a salt water aquarium – all these little fish.
old	46	I used to see thirty queen angelfish together, and marble groupers bigger than me.
	47	I suppose most guests wouldn't notice, it saddens you how few fish there are now.
	47	We used to see wahoo and tuna over the reef constantly.
	49	In the past I could hardly find a place to do a course in the shallows because there was so much staghorn and elkhorn coral.
	49	The reefs are declining. It worries me that I won't have a job in 10 years.
	51	If I put pictures of this reef twenty years ago and now next to each other you would cry.
	51	Now if you even see a tiger grouper you will jump with excitement. Twenty years ago you would jump in the water and be surrounded by fifteen of them.
	53	Bonaire has the best water quality. I see a lot of new growth.
	53	Now there is more algae, more anchor damage, more damage from development and storms. There is nothing left in the shallows.
	54	I've watched the reefs deteriorate. I've seen it plummet down.
older	57	There is nothing anymore. It's all gone.
	58	I used to see tiger groupers on every dive.
	61	If I was talking to customers I would never say the reefs are unhealthy because I know what it's like elsewhere.
	63	Yellowtail snapper used to be everywhere, like the flies of the ocean.
	67	It's balanced between dying and new growth.
	67	The marine life is as healthy as can be.
	67	Any site on this island is a nice dive.
	67	I have only seen three sharks here in 30 years of diving.

Table 5.3. Numbers of fishers and divers interviewed on Curaçao and Bonaire. Mean, with standard errors in parentheses, for current age, age and year when they started fishing or diving, the number of generations of fishers or divers in their families, number of years they have been fishing or diving, the number of years divers have been diving on Curaçao or Bonaire, and the number days per week fishing or number of dives per week.

	Fishers			Divers		
	Curaçao	Bonaire	Overall	Curaçao	Bonaire	Overall
Number of interviewees	126	51	177	112	99	211
young (15 to 30)	13	13	26	45	32	77
middle (31 to 45)	34	5	39	52	30	82
old (46 to 60)	58	16	74	13	31	44
older (61 to 81)	21	17	38	2	6	8
Mean age	48.6 (1.18)	51.0 (2.71)	49.2 (1.15)	34.3 (0.87)	39.7 (1.23)	36.8 (0.76)
Mean age started fishing or diving	13.7 (0.65)	10.1 (0.92)	12.6 (0.54)	21.9 (0.71)	22.5 (0.92)	22.2 (0.57)
Mean year started fishing or diving	1975 (1.21)	1969 (2.61)	1973 (1.16)	1997 (0.83)	1993 (1.17)	1994 (0.71)
Mean generations of fishers or divers in family	3.0 (0.14)	3.4 (0.17)	3.1 (0.11)	1.3 (0.55)	1.4 (0.53)	1.3 (0.04)
Mean years fishing or diving	34.6 (1.21)	40.8 (2.61)	36.4 (1.16)	12.4 (0.82)	17.0 (1.12)	14.6 (0.70)
Mean years diving on Curaçao or Bonaire				7.1 (0.09)	10.1 (0.95)	8.5 (0.66)
Mean fishing days per week	3.5 (0.18)	3.8 (0.27)	3.6 (0.15)			
Mean dives per week				8.8 (0.49)	7.0 (0.43)	8.0 (0.33)

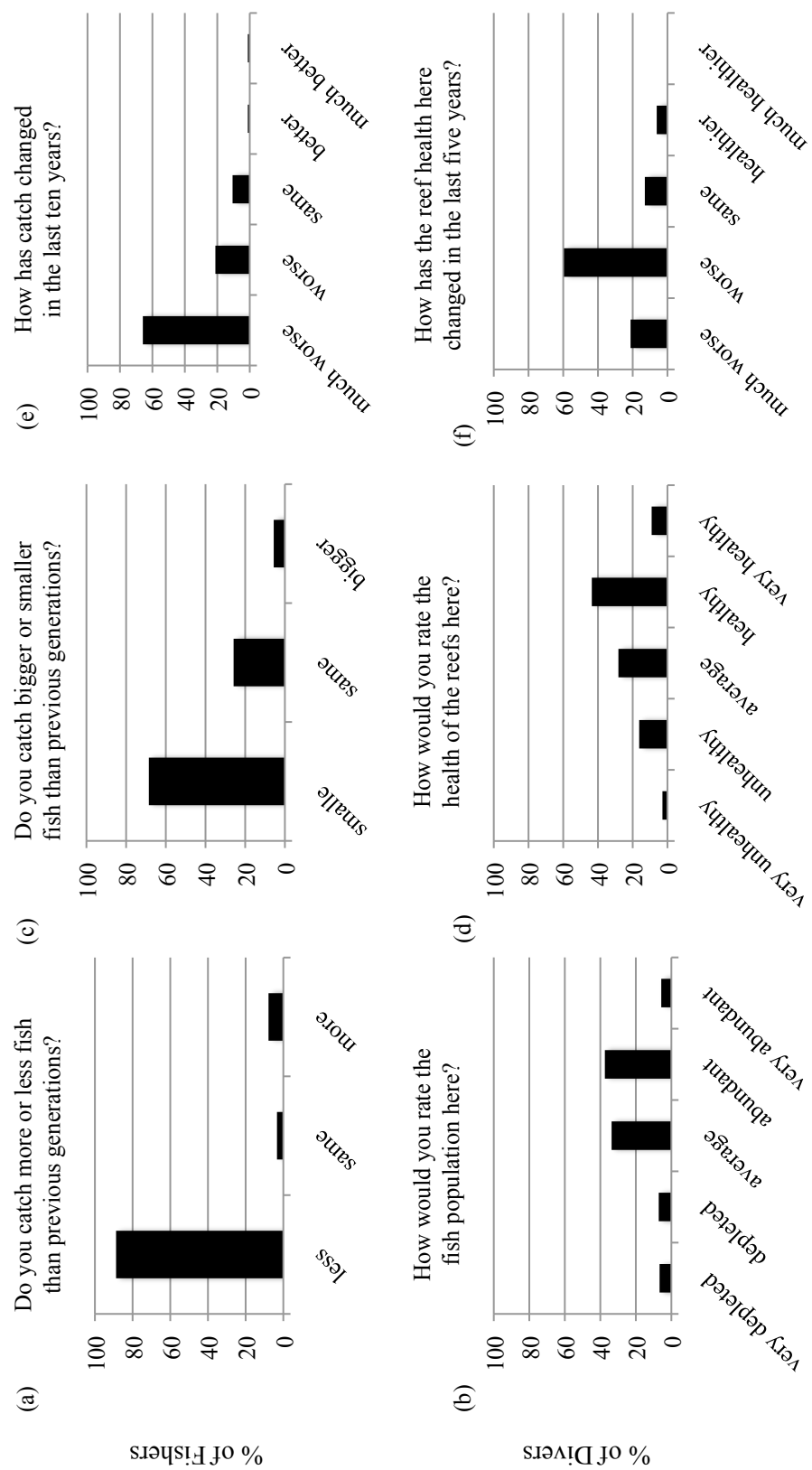
Table 5.4. Fish species or groups that received five or more mentions by divers and four or more mentions by fishers on Bonaire as fish they used to see or catch but now rarely or never see/catch.

# Divers	Fish name	# Fishers	Fish name
37	grouper (general)	13	yellowfin tuna
26	eel	11	bigeye tuna
21	lobster	11	blackfin tuna
10	barracuda	10	wahoo
8	tiger grouper	9	coney
6	large-bodied parrotfish	9	skipjack tuna
6	shark	8	nassau grouper
6	yellowtail snapper	8	grouper (general)
5	angelfish	7	dorado
5	octopus	5	rainbow runner
5	snapper (general)	5	yellowtail snapper
5	small-bodied parrotfish	4	blue marlin
5	nassau grouper	4	red snapper

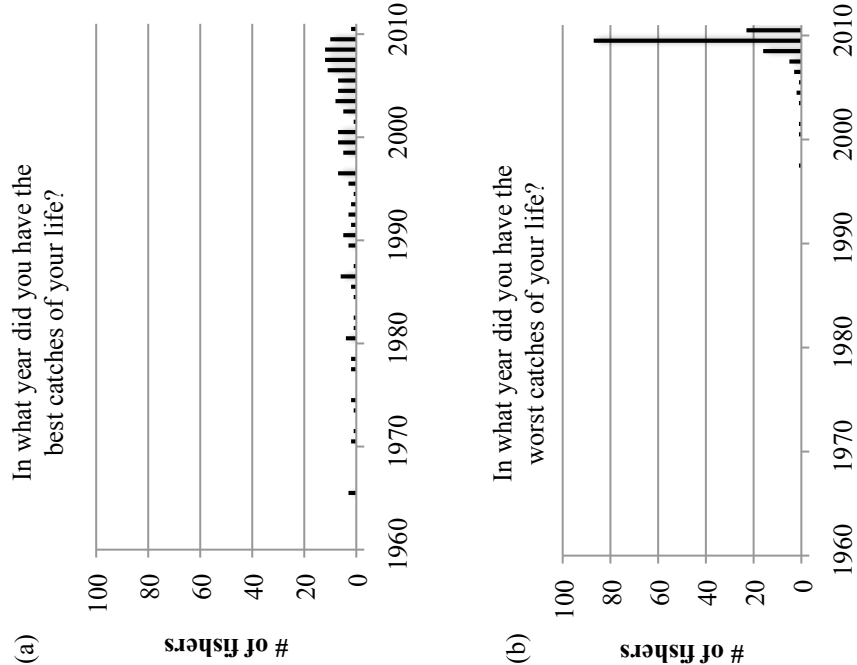
Table 5.5. Mean gear scores, reserve scores, and conservation score for fishers and divers with standard deviations in parentheses. Possible scores ranged from 0 to 100, with 100 representing all choices on the side of resource conservation.

	Gear Score	Reserve Score	Conservation Score
Fishers	53.6 (1.7)	36.2 (2.7)	46.5 (1.4)
Divers	75.0 (1.6)	69.4 (1.5)	72.5 (1.1)

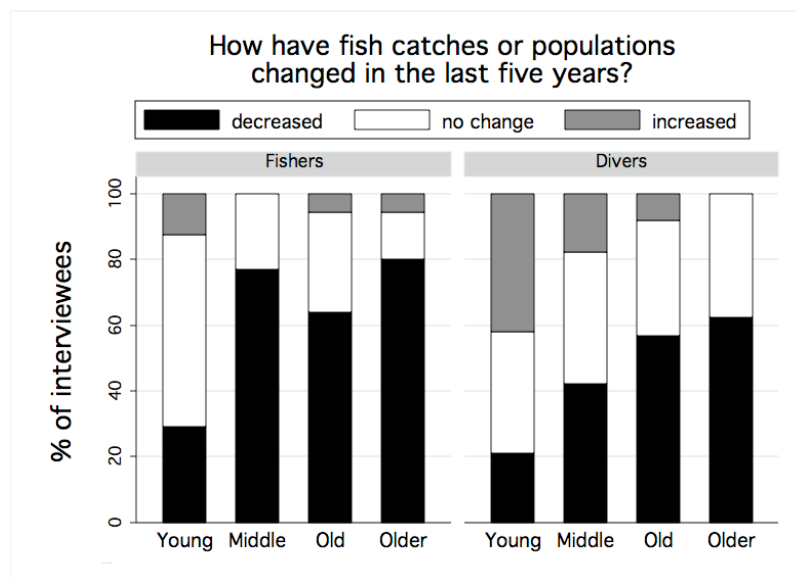
Graph 5.1. Responses of fishers (a,c,e) and divers (b,d,f) on Curaçao and Bonaire to survey questions about fish catch and coral reef and fish population health. Question (e) was only posed to fishers with ten or more years of experience. Question (f) was only posed to divers with five or more years of experience.



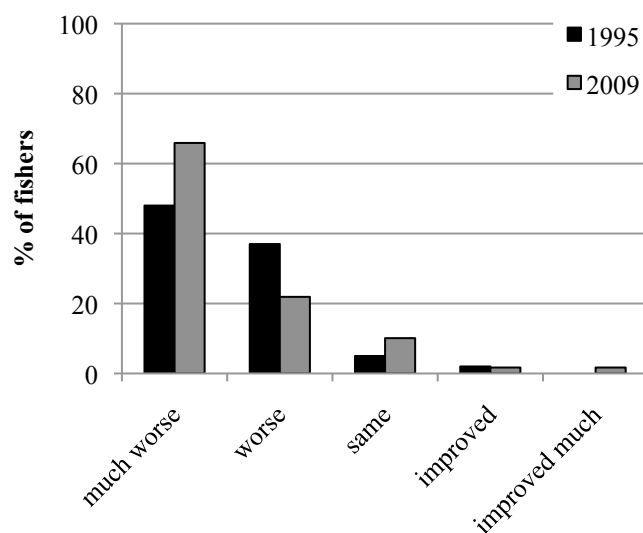
Graph 5.2. Years of lifetime (a) best and (b) worst catches reported by fishers on Curaçao and Bonaire. (c) Lifetime best year of fishing related to year started to fish. (d) Median of the best year for each start year as related to start year. Grey lines in (c) and (d) represent the trend if the start year was the also best year. Dashed line in (c) is linear best fit, slope 0.31 (SE 0.06, $p < 0.0001$). Dashed line in (d) is the linear best fit, slope 0.027 (SE 0.05, $p < 0.0001$).



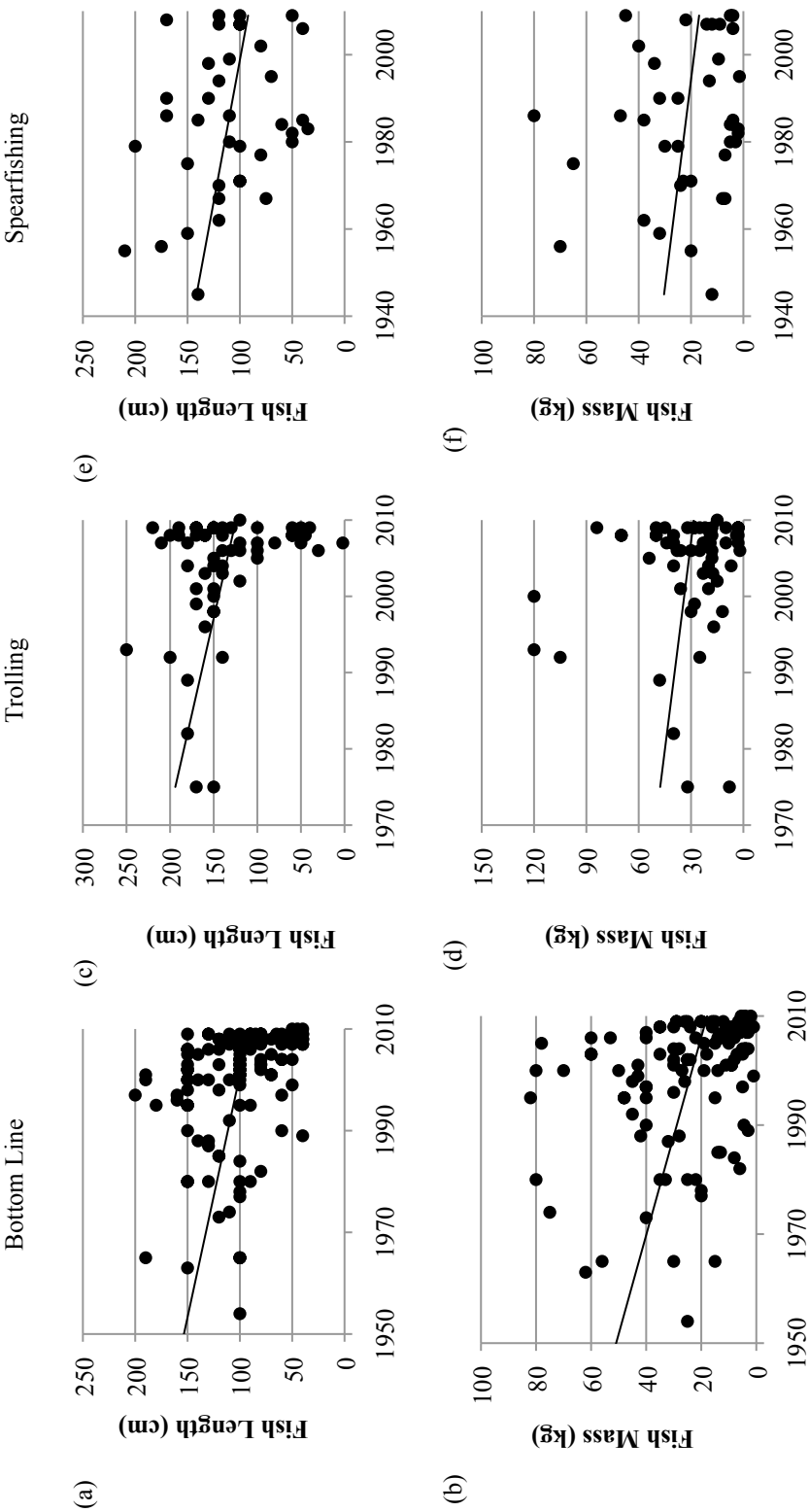
Graph 5.3. Responses by age group to the question of how fish catch (for fishers) or fish abundance (for divers) changed in the last 5 years. Only includes responses from individuals who have been fishing or diving on these islands for over five years.



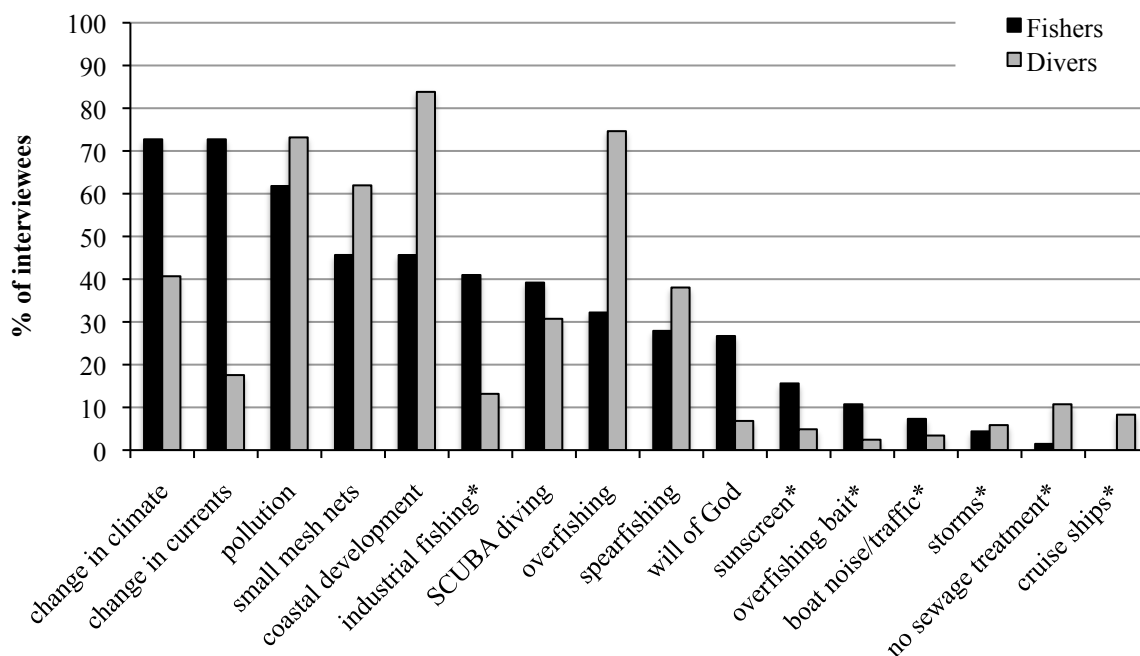
Graph 5.4. Responses of fishers on Curaçao in 1995 and in 2009 to the question of how fish catch has changed in the last 10 years. 1995 data points are interpolated from Figure 2 in Debrot and Nagelkerken 2000.



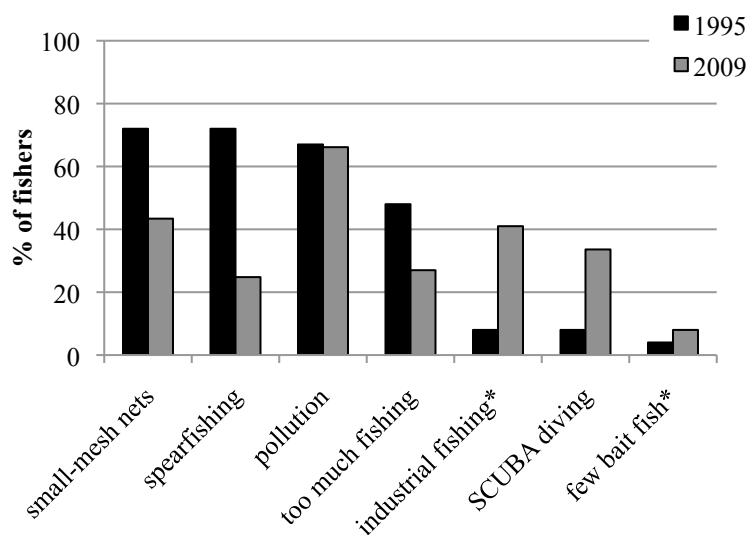
Graph 5.5. Length and mass of the largest fish fishers reported having caught in their lifetimes using bottom line (excluding pelagic species), trolling (excluding marlin), and spearfishing.



Graph 5.6. Percent of interviewees who acknowledged that each factor contributed to the decline in fish populations. Asterisks denote factors that interviewees were not questioned about directly, but that more than 5% of fishers or divers mentioned as additional contributing factors.



Graph 5.7. Perceived causes of catch declines present in the present study and in a data collected in 1995 (Debrot and Nagelkerken 2000 and the associated unpublished appendix) Asterisks represents volunteered responses (i.e. not yes/no questions) in both surveys.



APPENDIX A – Survey questions

Fisher Questions:

- How old were you when you first started fishing? OR What year did you start fishing?
- How old are you now?
- Is fishing your primary source of income? If no, was fishing ever your primary income?
- Was your father a fisherman?
- How many generations of your family are fishermen?
- Do you think you catch more fish or less fish than previous generations?
- Do you think you catch bigger or smaller fish than previous generations?
- Did you catch more fish this year or last year?
- In the last 5 years, each year are you generally catching: more fish, less fish, the same amount?
- Have you stopped fishing in some areas because the catch there is no longer good?
- Are there any species of fish you used to catch commonly and now don't catch or catch rarely?
- Do you think there are fewer fish in the ocean than there were 10 years ago?
- In the last 10 years, do you think fish catch is: much better, better, same, worse, much worse?
- What do you think has caused the decline in fish catch?
- Pollution? Too much fishing? Climate change? SCUBA Diving? Change in currents?
- Will of God? Small mesh nets? Spearfishing? Coastal development? Other things?
- What is the largest fish you ever caught in a trap? Species? Length? Kg? Year?
- What is the largest fish you ever caught with line? Species? Length? Kg? Year?
- What is the largest fish you ever caught with trolling? Species? Length? Kg? Year?
- What is the largest fish you ever caught with seine? Species? Length? Kg? Year?
- What is the largest fish you ever caught with gill net? Species? Length? Kg? Year?
- Does your fishing reduce the number of fish that will be in the ocean next year?

APPENDIX B – Survey questions about management of coral reef resources**Gear Questions:**

1. Should there be a limit to how small the mesh size can be on a trap?
2. Should rectangular holes be required in the side of fish traps to let small fish escape?
3. Should there be a limit how small mesh size can be on seine?
4. Should there be a limit how small mesh size can be on gill net?
5. Should trap fishing be banned?
6. Should snorkel fishing be banned?
7. Should fishing with seines be banned?
8. Should gill net fishing on reefs be banned?
9. Should gill net fishing everywhere around the island be banned?

Reserve Questions

1. Do you support no fishing areas?
2. Do you think there should be more and/or larger no fishing areas?
3. Do you think there should also be areas temporarily closed to fishing?
4. Should fishing on the reefs be banned?
5. Do you support no diving areas?
6. Do you think there should be more and/or larger no diving areas?
7. Do you think there should also be areas temporarily closed to diving?

Miscellaneous Management Questions:

1. Should there be a limit to the number of fishermen allowed to fish?
2. Should there be a limit to the number of divers allowed to dive?
3. Should catching juveniles be banned?
4. Should uncontrolled anchoring be banned if the government provided more buoys?
5. Are there any species you think should no longer be fished?

References

- Ainsworth, C.H., Pitcher, T.J., Rotinsulu, C. (2008) Evidence of fishery depletions and shifting cognitive baselines in Eastern Indonesia. *Biological Conservation* **141**, 848-859.
- Bak, R., Nieuwland, G., Meesters, E. (2005) Coral reef crisis in deep and shallow reefs: 30 years of constancy and change in reefs of Curacao and Bonaire. *Coral Reefs* **24**, 475-479.
- Bernard, H.R. (1994) *Research methods in anthropology: Qualitative and quantitative approaches*. Sage Publications, Thousand Oaks, CA, p. 585.
- Bohnsack, J.A. (2003) Shifting baselines, marine reserves, and Leopold's biotic ethic. *Gulf and Caribbean Research* **14**, 1-7.
- Bouchon, C., Portillo, P., Bouchon-Navaro, Y., *et al.* (2008) Status of Coral Reefs of the Lesser Antilles: the French West Indies, the Netherlands Antilles, Anguilla, Antigua, Grenada, Trinidad and Tobago. In: *Status of Coral Reefs of the World: 2008*. (Ed. C. Wilkinson), Global Coral Reef Monitoring Network and Reef and Rainforest Research Center, Townsville, Australia.
- Bunce, M., Rodwell, L.D., Gibb, R., Mee, L. (2008) Shifting baselines in fishers' perceptions of island reef fishery degradation. *Ocean & Coastal Management* **51**, 285-302.
- CBS (2010) Central Bureau of Statistics Netherlands Antilles. Vol. 2010.
- Debrot, A.O., Nagelkerken, I. (2000) User perceptions on coastal resource state and management options in Curacao. *Revista de Biologia Tropical* **48**, 95-106.
- Dilrosun, F. (2001) Progress report Curaçao fishery monitoring program. 13.
- Gardner, T., IM, C., Gill, J., Grant, A., Watkinson, A. (2003) Long-term region-wide declines in Caribbean corals. *Science* **301**, 958-960.
- Jackson, J.B.C. (1997) Reefs since Columbus. *Coral Reefs* **16**, S23-32.
- Jackson, J.B.C. (2001) What was natural in the coastal oceans? *Proceedings of the National Academy of Science USA* **98**, 5411-5418.
- Jackson, J.B.C., Kirby, M.X., Berger, W.H., *et al.* (2001) Historical overfishing and the recent collapse of coastal ecosystems. *Science* **293**, 629-638.
- Johannes, R.E., Freeman, M.M.R., Hamilton, R.J. (2000) Ignore fishers' knowledge and miss the boat. *Fish and Fisheries* **1**, 257-271.
- Knowlton, N., Jackson, J.B.C. (2008) Shifting baselines, local impacts, and global change on coral reefs. *Plos Biology* **6**, 215-220.

- Lozano-Montes, H.M., Pitcher, T.J., Haggan, N. (2008) Shifting environmental and cognitive baselines in the upper Gulf of California. *Frontiers in Ecology and the Environment* **6**, 75-80.
- Newman, M., Paredes, G., Sala, E., Jackson, J. (2006) Structure of Caribbean coral reef communities across a large gradient of fish biomass. *Ecol Letters* **9**, 1216-1227.
- Pandolfi, J.M., Bradbury, R.H., Sala, E., *et al.* (2003) Global trajectories of the long-term decline of coral reef ecosystems. *Science* **301**, 955-958.
- Pauly, D. (1995) Anecdotes and the shifting baseline syndrome of fisheries. *Trends in Ecology & Evolution* **10**, 430.
- Pinnegar, J.K., Engelhard, G.H. (2008) The 'shifting baseline' phenomenon: a global perspective. *Rev Fish Biol Fisheries* **18**, 1-16.
- Sáenz-Arroyo, A., Roberts, C.M., Torre, J., Cariño-Olvera, M., Enríquez-Andrade, R.R. (2005) Rapidly shifting environmental baselines among fishers of the Gulf of California. *Proceedings of the Royal Society B* **272**, 1957-1962.
- Sandin, S.A., Smith, J.E., DeMartini, E.E., *et al.* (2008a) Baselines and Degradation of Coral Reefs in the Northern Line Islands. *Plos One* **3**, Article No.: e1548.
- Sandin, S.T.A., Sampayo, E.M., Vermeij, M.J.A. (2008b) Coral reef fish and benthic community structure of Bonaire and Curacao, Netherlands Antilles. *Caribbean Journal of Science* **44**, 137-144.
- Schultink, R., Lindenbergh, S. (2006) Intensiviteit van de visserij op Curaçao.
- Sheppard, C. (1995) The Shifting Baseline Syndrome. *Marine Pollution Bulletin* **30**, 766-767.
- Stallings, C.D. (2009) Fishery-Independent Data Reveal Negative Effect of Human Population Density on Caribbean Predatory Fish Communities. *PLoS One* **4**, e5333.
- Stokes, M., Leichter, J., Genovese, S. (2010) Long-term declines in coral cover at Bonaire, Netherlands Antilles. *Atoll Research Bulletin* **582**.
- TCB (2009) Bonaire Tourism: Annual Statistics Report 2008.
- Turvey, S.T., Barrett, L.A., Hao, Y.J., *et al.* (2010) Rapidly Shifting Baselines in Yangtze Fishing Communities and Local Memory of Extinct Species. *Conservation Biology* **24**, 778-787.
- Wells, S.M. (1988) Coral Reefs of the World. Volume 1: Atlantic and Eastern Pacific. In: *UNEP Regional Seas Directories and Bibliographies*. UNEP/IUCN, IUCN, Gland, Switzerland and Cambridge, U.K./UNEP, Nairobi, Kenya, p. 373.
- Zaneveld, J.S. (1961) The fishery resources and the fishery industries of the Netherlands Antilles. *Proceedings of the Gulf and Caribbean Fisheries Institute* **14**, 137-171.

CHAPTER 6:

Time preferences and the management of coral reef fisheries:

Discounting the future value of a dollar and a reef

Abstract

To investigate whether there is a relationship between how individuals make financial decisions and how they make decisions about the use of natural resources, I conducted a time preference experiment with 161 fishers and 195 divers on the Caribbean islands of Curaçao and Bonaire. I found that divers have significantly higher individual discount factors (IDFs) than fishers, and the majority of interviewees exhibited neither present nor future bias. For divers, there was a significant positive correlation between mean IDF and support of regulations to manage fishing and diving, but there was no equivalent relationship for fishers. This implies that conservation views are influenced by multiple factors, and that individuals' preferred approaches to managing coral reefs are not necessarily formed using the same metrics as financial decisions. The policy implications of this research are (1) differences in time preferences between fishers and divers should be considered when developing management strategies, (2) management should attempt to shift fishers' incentives towards conservation – perhaps with transfer payments for reducing their effort and/or switching to low-impact gears, and (3) establishing property rights may be insufficient for conservation if fishers greatly discount the future, as that could lead to over-consumption of resources in the present.

Keywords: time preferences, discounting, fisheries management, fishers, SCUBA diving

Introduction

Individuals' time preferences (here, discounting and present bias) have been extensively researched as they pertain to demographic characteristics and financial decisions (Frederick et al., 2002). Recently, theories describing how individuals conceive of decisions and tradeoffs have begun to be applied more expansively, and research has considered the environmental implications of time preferences (Hardisty and Weber, 2009). Much of the environmental research to date has focused on how social discounting could affect policy approaches for mitigating global warming (reviewed in Carson and Roth Tran, 2009). Less research has focused on the marine realm, although notable exceptions include applications of time preference concepts to marine protected area design (Grafton et al., 2005, Sanchirico et al., 2006) and marine ecosystem restoration (Sumaila, 2004). Research on the relationship between the discount rates of *individuals* and marine resource management is sparse.

Open access problems aside, one might expect that individuals who are more patient and less present-biased with regard to financial decisions (i.e. those who value the future more highly) would also be more inclined towards resource conservation. Conversely, one might expect that individuals who are less patient and more present-biased would be more inclined towards unsustainable levels of resource exploitation. Little empirical work has focused on this theory as pertains to fisheries management. Substantially more work has been done on the risk preferences of fishers (Eggert and Tveteras, 2004, Bockstael and Opaluck, 1983, Opaluck and Bockstael, 1984, Smith and Wilen, 2005, Eggert and Martinsson, 2004, Eggert and Lokina, 2007, Mistiaen and Strand, 2000) than on the time preferences of fishers.

To my knowledge, there are only two published studies that present fishers' discount factors. Both of those studies elicited individual discount factors (IDFs) using hypothetical choices between various fisheries management regimes and the theoretical future income streams associated with those regimes (Akapalu, 2008, Curtis, 2002). There do not appear to be

any published studies presenting time preferences elicited from SCUBA divers. Thus, the research presented here seems to represent the first attempt to elicit fishers' and divers' time preferences using incentivized choice experiments (i.e. price lists associated with actual monetary payments), and further, to explore the relationships between experimentally measured discount factors and stated resource management preferences.

I elicited time preferences from fishers and professional SCUBA divers in Curaçao and Bonaire, islands in the southeastern Caribbean. These two professions were chosen because both are dependent on the health of ocean resources for their incomes – fishers for the abundance of their catches and divers for attracting tourists. These neighboring islands are former Dutch colonies with similar histories of resource exploitation and similar marine ecosystems. The time preference experiment was paired with a lengthy socioeconomic survey that included questions on fishing and diving practices, perceptions of fish population trends (see Chapter 5), and level of support for management options such as gear restrictions and marine reserves (see Chapter 7). Here, I evaluate demographic explanations for differences in time preferences and consider whether time preferences are related to fishers' and divers' preferred strategies for managing coral reefs.

Methods

Socioeconomic survey approach

From August through December 2009, I conducted interviews with fishers and professional divers (i.e. dive instructors, divemasters, and dive guides) on Curaçao. In April and May 2010, I interviewed fishers and professional divers on Bonaire. Because there are no complete lists of the fishers or divers on either island, stratified random sampling of these groups was not possible. Instead, I conducted interviews opportunistically, attempted to survey these groups as exhaustively as possible, and sought representation of all age groups.

Interviewees were identified via recommendations from local contacts, approaching people at fishing docks and in dive shops, and requesting the contact information for additional individuals at the end of each interview in what is termed a snowball sampling technique (Bernard, 1994). I conducted all interviews in person. All divers were fluent in English, and a Papiamento-Dutch-English translator was available for all fisher interviews.

I conducted 388 interviews: 126 fishers on Curaçao, 51 fishers on Bonaire, 112 divers on Curaçao and 99 divers on Bonaire. Based on the number of I interviews I conducted, the number of potential interviewees I identified but with whom I was unable to schedule interviews, and my general knowledge of the fishing and diving communities, I estimate there are approximately 200 fishers on Curaçao, approximately 80 fishers on Bonaire, approximately 120 professional divers on Curaçao, and approximately 130 professional divers on Bonaire. Based on these estimates, I interviewed 63% and 65% of the fishers on Curaçao and Bonaire respectively, and 86%, and 83% of the divers on Curaçao and Bonaire respectively.

Of interviewees, eight fishers and five divers declined to participate in the time preference experiment because they refused to have their participation in the interview be at all associated with a monetary payment. There were nine fishers and eleven divers who had multiple switch points in one or more price lists. Because such responses imply either that this is an inappropriate approach for measuring IDFs for those interviewees, or that they did not properly understand the questions, those individuals are not included in this analysis. Thus, the responses of 161 fishers and 195 divers are examined here.

Eliciting time preferences

Methods for eliciting time preferences have become well-honed, and the research presented here utilized the best techniques currently available in attempt to capture the most accurate responses (Coller and Williams, 1999). Price lists accompanied by real payments were

used to elicit time preferences. At the end of each socioeconomic interview, participants were asked twenty-one questions – three price lists were used, each with seven questions (Appendix A). All price lists presented choices between sooner, smaller payments, and later, larger payments. Payments ranged from twenty to fifty florins (Fl.; 1 USD = Fl. 1.75). This maximum payment of Fl. 50 was chosen because it is a denomination of the local currency, so participants should have been familiar with its purchasing power. Additionally, the amount is not so high as to make the experiment cost prohibitive, but high enough that it is roughly equivalent to a fisher or diver's daily income, thus one would not expect all participants to be indifferent between payment choices.

The quantities of money offered are consistent across price lists. All sooner payments ranged from Fl. 50 down to Fl. 20 while all later payments were held constant at Fl. 50. The difference among the price lists was the date at which payments were to be distributed. The first price list contains choices between payments on the coming Friday and payments two weeks from Friday. The second price list contains choices between payments Friday and one month from Friday. The third price list contains choices between payments two weeks from Friday and a month from Friday. The instructions and all questions were read aloud in the interviewee's preferred language.

To encourage interviewees to carefully consider their responses to the time preference questions, each interviewee was offered a cash payment in accordance with their answer to one of the twenty-one questions. After responding to all questions, participants chose a numbered chip from a sack, and the quantity of their payment was determined according to how they answered the question corresponding with the number on the chip. For example, an interviewee who chose the chip marked with number seven, and who in response to question seven chose to receive Fl. 50 two weeks from Friday over Fl. 20 on Friday, would then actually be offered Fl. 50 two weeks from Friday.

I employed front end delays, that is, no payments were made at the time of interview. This means of equating the transaction costs of choosing the sooner and later payments reduces the dependence of responses on level of trust for the researcher (Cardenas and Carpenter, 2008). All interviewees were required to retrieve their payments at a specified future date, time and location. On Curaçao, I distributed payments on Friday afternoons at the office of Dienst Landbouw, Veeteelt & Visserij (LVV), where the fisheries department is located. On Bonaire, I distributed payments on Friday afternoons at the office of Stichting Nationale Parken (STINAPA), the headquarters of the island's marine park. Each interviewee was given a card stating the date and time their payment could be picked up along with directions to the payment distribution location. To avoid misunderstandings, each interviewee was also asked to print and sign their name on a card (written in either English or Papiamentu) that stated the payment amount, pickup date, and pickup location.

Calculating discount factors

Individual discount factors (IDF) were calculated based on participant responses to questions in the three price lists: IDF_1 , IDF_2 , and IDF_3 correspond with price lists one, two, and three respectively. For the point in each price list where the participant switched between preferring the sooner to preferring the later payment, I took the mean between their last preferred sooner payment amount and the first preferred later payment amount. I then divided that mean by Fl. 50, the highest payment choice in each question, yielding discount factors from ≥ 1.0 down to ≤ 0.4 (Table 6.1). For example, a participant who chose the sooner payments until asked to choose between Fl. 50 in two weeks from Friday and Fl. 20 on Friday, and at which point chose to wait two weeks to receive Fl. 50, would have a mean switch point of 25 (the mean of the Fl. 30 and Fl. 20 sooner payment amounts between which the switch was made) which when divided by 50 yields a discount factor of 0.5.

A participant who chose later payments in response to all questions, even when given the choice between Fl. 50 on Friday and Fl. 50 in 2 weeks, would have a discount factor of 50/50, which we notate as ≥ 1.0 because it cannot be assigned an upper bound. A participant who chose sooner payments in response to all questions would have a discount factor of 20/50, which we notate as ≤ 0.4 because it cannot be assigned a lower bound. The mean of IDF_1 , IDF_3 , and the square root of IDF_2 , termed IDF_m , was used to examine the relationships between discount factors, demographics, and management opinions. The square root of IDF_2 is taken to transform the one-month discount factor, which is essentially two periods of a two-week discount factor, into a two-week discount factor, thereby making it comparable to IDF_1 and IDF_3 . To examine the relationship between the two-week discount factors and the one-month discount factor, IDF_1 was multiplied by IDF_3 to transform it into a one-month discount factor, IDF_{2a} , comparable with IDF_2 .

Individuals were categorized as present-biased, future-biased, or non-biased based on the relationship between IDF_1 and IDF_3 . These are the IDFs calculated from price lists with a two-week difference in payment dates, but with IDF_3 having an additional two week front-end delay.

Present-biased: $IDF_1 < IDF_3$
 Future-biased: $IDF_1 > IDF_3$
 Non-biased: $IDF_1 = IDF_3$

Individuals for whom IDF_1 was smaller than IDF_3 are considered present-biased. Individuals for whom IDF_1 was larger than IDF_3 are considered future-biased. Individuals for whom IDF_1 is equal to IDF_3 are considered non-biased.

Eliciting conservation preferences

As part of the larger survey, all participants were asked their opinions of a variety of marine management options (see Appendix B). Questions focused on fishing gear restrictions

(i.e. requiring modifications to certain types of fishing gear or banning gear types all together) and area restrictions (i.e. temporary or permanent no fishing or no diving reserves). Using the nine gear questions and seven reserve questions, “gear scores” and “reserves scores” were calculated for each individual based on the percentage of gear restrictions and area restrictions they supported. Using responses to gear and reserve questions and five additional miscellaneous management questions, an overall “conservation score” was calculated for each individual. The maximum value for each score is 100 (i.e. all responses favored use restrictions and resource protection) and the minimum value is zero.

Revealed conservation preferences

Fishers utilize several types of fishing gear. Most commonly, these gears are hook-and-line, trolling, fish traps, spearguns, gill nets, and beach seines. Hook-and-line and trolling generally cause less environmental harm (in terms of bycatch of juveniles and non-target species and habitat damage) than do fish traps, spearguns, gills nets, and beach seines. Thus, I term the former low-impact gears, and the latter high-impact gears. Low-impact gears have high risk of zero catch, but also a chance of valuable catch; they tend to catch low numbers of high-value fish. High-impact gears have low risk of zero catch, but also low chance of valuable catch; they tend to catch high numbers of low value fish. High-impact gears are often less time intensive per kilogram caught (traps and nets need not be constantly attended while they are fishing). Because most fishers utilize multiple types of fishing gear, a composite “gear impact score” was calculated for each fisher to enable examination of the relationship between gear impact scores and IDFs. For each high-impact gear type, fishers receive zero points if they do not use it, 0.5 points if they used to use it, and one point if they currently use it, for a maximum of 4 points and a minimum of zero.

Data analysis

χ^2 goodness-of-fit tests were used to identify differences between professions and islands in the proportions of interviewees who were married, had children, had an employed spouse, and who relied on fishing or diving as their primary income. Where sample sizes in some categories were small, Fisher's exact tests were additionally used to test for significance. Across islands and professions, regressions were used to identify relationships between IDF_m and demographic characteristics, present bias, and management scores, between the two-week and one-month discount factors (i.e. IDF_2 versus IDF_{2a}), and between management scores and demographic characteristics. Because time preference parameters are difficult to accurately estimate, even using the best available techniques, parameter relationships with p-values less than 0.01 are presented as significant and potential explanations for those relationships are discussed.

Results

Interviewee demographics

The mean age of interviewed fishers was 48.7 years, significantly older than divers, for whom the mean age was 37.0 ($p < 0.001$, Table 6.2). The mean age of fishers was not significantly different between islands, but divers on Bonaire are significantly older than divers on Curaçao ($p < 0.001$). Fishing was the primary source of income for 28% of interviewed fishers, a significantly smaller percentage than the 85% of divers for whom diving is the primary income ($p < 0.0001$). The proportion of fishers who rely on fishing as their primary income did not differ significantly between islands. Ninety-two percent of divers on Bonaire rely on diving for their primary income, significantly more than the 79.3% who do so on Curaçao ($p = 0.014$). Mean annual incomes of interviewees were approximately Fl. 26,000 and not significantly different between professions or islands. However, because income data were

self-reported and there was such great variation within the responses of an individual to various income questions, estimates of error are not presented and income data are not used further in the present analysis.

Fishers were more likely than divers to be married and to have children (both $p < 0.003$). Of those who were married, divers were more likely than fishers to have a spouse who was employed ($p < 0.001$). Proportion of fishers and divers who were married, had children, and had an employed spouse did not differ significantly between islands. Divers were significantly more likely than fishers to have a bank account, to have a credit card, and to have a friend who would loan them Fl. 50. (all $p < 0.001$). Of participants who could borrow Fl. 50 from a friend, fishers were significantly more likely to say they would have to pay interest on such a loan ($p = 0.0001$).

Discount factors

Fishers' discount factors were significantly lower than those of divers (Graph 6.1). The mean IDF_m for fishers was 0.86 (SE 0.014) compared to 0.93 (SE 0.008) for divers. For both fishers and divers, mean IDF_1 had the highest value of all calculated $IDFs$. Mean IDF_{2a} was the lowest, and was significantly lower than mean IDF_1 ($p < 0.001$ for fishers and divers, Table 6.3). IDF_m was significantly lower for fishers on Bonaire than Curaçao ($p = 0.002$), but inter-island differences were not significant for divers. For fishers, IDF_m was positively correlated with having a bank account ($p = 0.02$). For divers, IDF_m was positively correlated with being married ($p = 0.044$).

Divers were more likely than fishers to choose the later payment even when the sooner and later payment amounts were both Fl. 50 (Graph 6.2). Fishers were more likely than divers to choose the sooner payment for all questions in a price list. The majority of both fishers and divers have discount factors ≥ 0.98 , however, the distribution of diver $IDFs$ exhibits an

essentially monotonic decline from 1.0 down to ≤ 0.4 , while that of fishers has a somewhat a tri-modal distribution with additional peaks at 0.75, and at ≤ 0.4 . The cluster of fishers at an IDF of ≤ 0.4 represents 10% to 17% of participants depending on the price list, 17% corresponding with the one-month time lag of IDF_2 . The cluster of fishers at an IDF of 0.75 represents approximately 10% of participants in each price list.

Fifteen percent of fishers and 27% of divers had the same switch point in all three price lists. The mean elicited one-month discount factor (IDF_2) is significantly higher than the mean calculated one-month discount factor (IDF_{2a}) for fishers and divers (both $p < 0.001$). However, IDF_2 was equal to IDF_{2a} for 19% of fishers and 35% of divers, which is due to those individuals selecting different switch points across the price lists that result in the same IDF.

Present bias

Distributions of bias were not significantly different between professions or islands. For two-thirds of both fishers and divers, IDF_1 was equal to IDF_3 , indicating those interviewees were non-biased (Graph 6.3). An additional 22% of participants were future-biased, and the remaining 12% were present-biased. Present-biased divers had significantly lower IDF_m than non-biased and future-biased divers ($p = 0.018$). There were no significant relationships between IDF_m and bias for fishers.

Management scores

The mean gear scores, reserve scores, and conservation scores were all significantly higher for divers than for fishers (all $p < 0.0001$, Table 6.4). For divers, gear score and conservation score were positively correlated with IDF_m ($p = 0.088$ and $p = 0.093$, respectively). There were no significant relationships between management scores and IDF_m for fishers, although there were positive correlations between gear and conservation scores and fishers'

ages (both $p < 0.020$). For divers, reserve score was negatively correlated with age ($p = 0.072$). Relationships between management scores and present bias were not significant for either fishers or divers.

Fishing gears used

There were no significant relationships between the destructiveness of fishing gears used, as measured by the gear impact score, and fishers' discount factors or present bias.

Restricting their own resource use

Divers were significantly more likely than fishers to support both a limit on the number of fishers and a limit on the number of divers (both $p < 0.02$). Forty-two percent of divers supported a limit on the number of divers, whereas only 1% of fishers supported a limit on the number of fishers.¹ Fishers who used destructive gears had significantly lower gear scores than those who did not ($p = 0.032$), reflecting a reluctance to have restrictions placed on their use of these gears. Fishers were more likely than divers to support no diving areas ($p < 0.0001$) and vice versa for no fishing areas ($p < 0.0001$). Although, as far as restricting their own behavior, 63% of divers supported no diving areas compared to 40% of fishers who supported no fishing areas. On Bonaire, where no fishing and no diving areas already exist, the same relationship holds, with fishers more likely to support additional no diving areas ($p = 0.04$) and divers more likely to support additional no fishing areas ($p = 0.008$). Divers on Bonaire were more likely to support additional no diving areas (51% support) than fishers were to support additional no fishing areas (32% support). Over 80% of divers on each island support both temporary no

¹ It should be noted that a restriction on divers is likely to restrict the number of tourist divers, and thereby the number of potential customers, but not necessarily the number of professional divers, thus affecting them somewhat indirectly. A restriction on the number of fishers could directly prevent the interviewee from fishing.

diving areas and temporary no fishing areas, significantly more support than these measures received from fishers (both $p < 0.0001$).

Discussion

Fishers vs. divers

Overall, divers have higher discount factors than fishers, with no significant effect of age. The explanation for this is not immediately clear. Some research has identified a positive relationship between discount factor and income (discussed in Carson and Roth Tran, 2009), so this result could reflect the fact that divers generally have higher expected lifetime incomes than fishers. Professional divers frequently work in the dive industry to temporarily support themselves while living abroad, tend to be better educated than fishers, and often have higher-paying jobs they can return to and/or family members (parents or spouses) to provide financial assistance while they pursue professional diving. Professional divers in Curaçao and Bonaire are generally young (under 40), unmarried, foreigners (mostly Dutch) without children. Overall diver demographics likely remain fairly consistent over time despite the high turnover within the professional diving community.

In contrast, there is almost no turnover of fishers, although the proportion of time an individual allocates to fishing often varies seasonally and inter-annually based upon the catch and the existence of alternative employment opportunities. Fishers have fewer financial resources than divers, and often have more individuals to support with those resources that divers do. Fishers' greater level of financial constraint seems to be manifested their lower discount factors. In fact, fishers who did not have bank accounts had a significantly lower IDF_m than fishers with bank accounts. However, evidence in the literature for the correlation between poverty and time preferences is mixed (Cardenas and Carpenter, 2008).

Discount factors of fishers on Bonaire were lower than those of their counterparts Curaçao. One potential explanation for this is that fishers on Bonaire, which is a much smaller economy and a much less industrialized island, have fewer alternative employment options, and as such feel more financially constrained.

Individuals largely offered similar responses across price lists. Perhaps the differences in days until payment (Friday versus two weeks versus a month) were not large enough to elicit different switch points. Time periods on the order of six months or a year may have produced greater differentiation in responses between price lists. Thus, the relatively low occurrence of present bias, and the differences between IDF_2 and IDF_{2a} may actually be a display of consistency across price lists that individuals did not perceive as presenting substantially differing choices.

The cluster of fishers at an IDF of ≤ 0.4 is likely an artifact of the truncation of each price list after seven questions, the last of which asks about Fl. 20 versus Fl. 50. If the range of sooner payments had included amounts less than Fl. 20, some of the participants may have chosen additional lower, sooner payments, resulting in discount rates lower than 0.4, thus dispersing that peak. The peak at 0.75, however, may be meaningful and not an artifact of the experimental design.

An IDF of 0.75 corresponds with a preference of Fl. 40 sooner over Fl. 50 later, but a preference of Fl. 50 later over Fl. 35 sooner. One potential explanation for this peak is provided by the fact that currency quantities are often mentally compared against the value of oft purchased items. Polar, which is the most popular beer on both islands, is priced from Fl. 36 to Fl. 38 per case, is one likely candidate for such a calibration. Although the data I collected cannot prove more than correlation, three fishers did explicitly mention this as the rationale for their switch point.

Comparison with previous studies

Despite all the research that has focused on measuring time preferences, and due in part to widely varying elicitation methods, honing in on a “normal” range of discount factors has been elusive, and published IDFs span the entire gamut from below zero to infinity (Frederick et al., 2002). It is thus difficult to meaningfully contextualize the discount factors I present here within the behavioral economics literature. As compiled by Frederick et al. (2002), seven studies published between 1978 and 2002 elicited discount factors using choice sets associated with real monetary payments. Those studies produced a range of discount factors from 0.0 to 1.01. The range of IDFs presented here, from 0.4 to 1.0, is truncated due to the experimental design, precluding direct comparison with previous research. The broad range of values I elicited may be due in part to the use of time horizons less than a year (Frederick et al., 2002).

The two previous studies that report experimentally measured discount factors of fishers found mean values substantially lower than those presented here. As measured with questions about future profit scenarios that would result from different fishery management approaches, fishers in the Irish Sea had a mean discount factor of ~0.7 (Curtis, 2002), and fishing boat skippers in Ghana had a mean discount factor of 0.43 (Akapalu, 2008). Because those two studies used different elicitation methods than the price list approach used here, it cannot be determined whether the higher discount factors I measured are indicative of important differences in cultural, economic, or fisheries management contexts.

Present bias

Fishers and divers exhibited similar distributions of bias, with future bias more common than present-bias for both professions. There are several possible interpretations for the large proportion of individuals exhibiting future-bias. Perhaps individuals were using the experimental payment as a commitment device for saving. For example, one interviewee said

that he did not have a girlfriend now but that he might in two weeks, so if he waited then he would have money to take her out to dinner. Motivation to wait for payment could be due in part to the highly variable nature of fisher and diver incomes, with fishers depending on catches and divers depending partly on tips. Alternately, interviewees may have been hesitant to admit a preference for receiving money sooner, due to pride. This hesitation could have been exacerbated by the fact that the participants were mostly male and the interviewer was a young female. Additional possible explanations for future-bias include whether the interviewee had recently received a paycheck, whether divers had recently received a good tip, and whether fishers recently had a good catch. Indeed, it is no surprise that human decisions can be influenced by the experimental process and context and by motivations such as the desire to appear competent, and therefore may not solely reflect monetary preferences (e.g. Levitt and List, 2007, Bowles, 1998).

Time preferences and management preferences

It stands to reason that individuals with higher discount factors, implying greater patience with financial decisions, might also be more patient with the use of marine resources. That is, they may be willing to accept restrictions on their current resource use in order to have greater ecosystem health and productivity in the future. For divers, I was able to identify this correlation between higher discount factors and greater willingness to restrict their use of the marine environment as measured in management scores. Furthermore, younger divers had higher reserve scores, which is promising since it implies the younger generation is more supportive of spatial closures.

I did not identify any relationships between fishers' IDFs and management scores. There were also no significant relationships between fishers' time preferences and the types of fishing gears they used. However, older fishers were more supportive of gear restrictions and of

management measures in general compared to younger fishers. Perhaps this is because older fishers have witnessed the decline of their fishery, and are therefore more willing to accept fishery restrictions in the hope that such efforts would result in recovery of the fishery to previous catch levels (see Chapter 5). Regardless, fishers overall (1) have lower discount rates than divers, and (2) appear less inclined than divers toward long-term resource conservation. The lack of a direct correlation between fishers' discount rates and support for resource management implies that their conservation views are influenced by multiple factors, and that individuals' management preferences may not be formed using the same metrics as financial decisions.

It should be noted that questions about gear restrictions applied only to limiting types of fishing gear and there were no equivalent questions about limiting diving. It is not surprising that fishers are less likely to want to restrict their own activity than divers are to want to restrict the activity of fishers, and this is likely reflected in the gear scores. Yet, questions on area restrictions were asked about both fishing and diving, and divers were more likely to accept restrictions on where they could dive than fishers were to accept restrictions on where they could fish. This is evidence, albeit limited, of divers' greater patience with resource use relative to fishers.

Policy implications

If these direct and indirect relationships between time preferences and management preferences are robust, there are implications for the effectiveness of various policy approaches. The differences between the time preferences of fishers and divers indicate that managing these two groups differently might be appropriate, and that the financial constraints and relative financial impatience of fishers should be accounted for in designing management. More specifically, my results suggest two approaches for increasing fishery sustainability that are

likely to be successful. First, policy could attempt to shift fishers' incentives towards conservation – perhaps with transfer payments for reducing their effort and/or switching to low-impact gears. If dive industry employees are more patient than fishers and have higher valuations of conservation, then perhaps they, or the dive industry more broadly, could be the source of payments to fishers. This notion is timely in the context of the dive fee that exists on Bonaire and may soon exist on Curaçao. Every individual who dives or snorkels on Bonaire is required to buy an annual marine park tag for 25 USD, the funds from which are used for marine park management. The plan for Curaçao is similar; an annual fee would be used to fund enforcement of marine regulations. Utilizing a portion of these funds to pay fishers to reduce or cease use of high-impact gears could be a cost-effective conservation approach. For example, this might be a mechanism for a buyout of the gill net fishery, which inflicts damage on shallow reef ecosystems and is the gear type most abhorred by divers (see Chapter 4).

Second, establishing property rights may not be sufficient for conservation. Ownership is presumed to lead to improved resource stewardship, and in recent years the fisheries economics community has lavished attention upon property rights-based management approaches such as cooperatives, individual transferable quotas (ITQs), and territorial use rights in fisheries (TURFs). However, if fishers greatly discount the future then they may over-consume resources in the present despite the incentive for sustainable use that is associated with ownership. This implies the need for a top-down regulatory approach.

Interestingly, discount factors have been negatively correlated with likelihood of violating fisheries regulations – fishers who are less patient and discount the future more are more likely to break the rules (Akapalu, 2008). Furthermore, likelihood of violating fisheries regulations has been negatively correlated with the perceived legitimacy of the regulation, and positively correlated with likelihood of detection (Akapalu, 2008). This suggests that property

rights without strict catch limits, strong enforcement, and robust community buy-in will likely lead to overexploitation, just as occurs in open access fisheries.

Ineffective management of coral reef fisheries can result in overfishing, overcapitalization, and low profits (Munro and Scott, 1985), can facilitate a shift to an algal-dominated ecological state (Hughes, 1994, Knowlton, 2004), and can jeopardize food security (Sadovy, 2006, Pauly, 2006). It is therefore important for coral reef management efforts and for future economic research to consider how to address the myriad factors that influence individuals' resource use patterns, and to endeavor to better align financial incentives with sustainability.

Acknowledgements

The largest part of my gratitude goes to the fishers and divers who participated in this project. I am also very appreciative of the efforts of my primary translators: Kurt Brown, Jerry Vollebregt, Mark Brown, and Dustin Abraham. Faisal Dilrosun of Dienst Landbouw, Veeteelt & Visserij (LVV) and Ramon de Leon of Stichting Nationale Parken (STINAPA) offered key logistical support. Charles Sprenger inspired this project and assisted with experimental design. Professors Theodore Groves and James Andreoni offered valuable insight into economic theory, data analysis, and interpretation of results, and were wonderfully patient with a marine biologist dabbling in their field.

Chapter 6, in full, is currently being prepared for submission for publication of the material. Johnson, Ayana Elizabeth. The dissertation author was the sole investigator and author of this material.

Table 6.1. Price list switch points and their associated discount factors.

Survey responses elicited	Midpoint between switch questions	Discount Factor
prefers Fl.50 later over Fl. 50 sooner	50	≥ 1.0
prefers Fl. 50 sooner over Fl. 50 later	49	0.98
prefers Fl. 48 sooner over Fl. 50 later	46	0.92
prefers Fl. 44 sooner over Fl. 50 later	42	0.84
prefers Fl. 40 sooner over Fl. 50 later	37.5	0.75
prefers Fl. 35 sooner over Fl. 50 later	32.5	0.65
prefers Fl. 30 sooner over Fl. 50 later	25	0.5
prefers Fl. 20 sooner over Fl. 50 later	20	≤ 0.4

Table 6.2. Key demographic information for fishers and divers interviewed on Curaçao and Bonaire. Mean interviewee age, with standard error in parentheses

Profession	Fishers			Divers		
Island	Curaçao	Bonaire	Overall	Curaçao	Bonaire	Overall
Number of interviewees	116	45	161	106	89	195
Mean age	48.2 (1.22)	50.1 (2.84)	48.7 (1.18)	34.2 (0.89)	40.3 (1.30)	37.0 (0.79)
Primary income source	27.0%	32.1%	28.12%	79.3%	92.0%	85.0%
Married	54.0%	45.5%	51.6%	34.3%	36.1%	35.1%
Children	78.3%	68.9%	75.6%	26.4%	26.1%	26.3%
Spouse employed	52.5%	52.4%	52.4%	81.1%	87.5%	84.1%

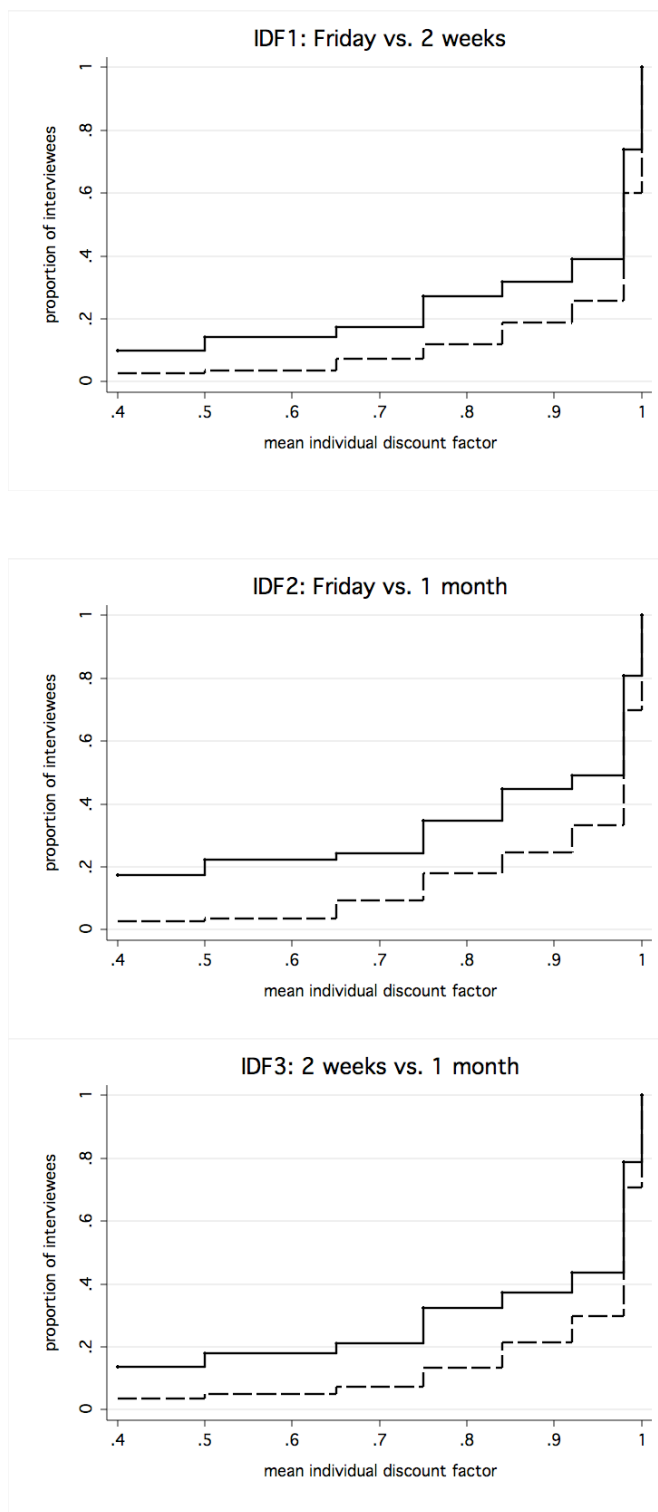
Table 6.3. Mean, with standard errors in parentheses, IDFs for interviewed fishers and divers as calculated from each of the three price lists (IDF_1 , IDF_2 , and IDF_3); from the result of multiplying IDF_1 and IDF_3 (IDF_{2a}); and from the mean of IDF_1 , IDF_3 and the square root of IDF_{2a} (IDF_m).

	IDF_1	IDF_2	IDF_3	IDF_{2a}	IDF_m
Fishers	0.86 (0.016)	0.81 (0.018)	0.89 (0.011)	0.75 (0.022)	0.86 (0.014)
Divers	0.93 (0.010)	0.91 (0.010)	0.95 (0.006)	0.87 (0.013)	0.93 (0.008)

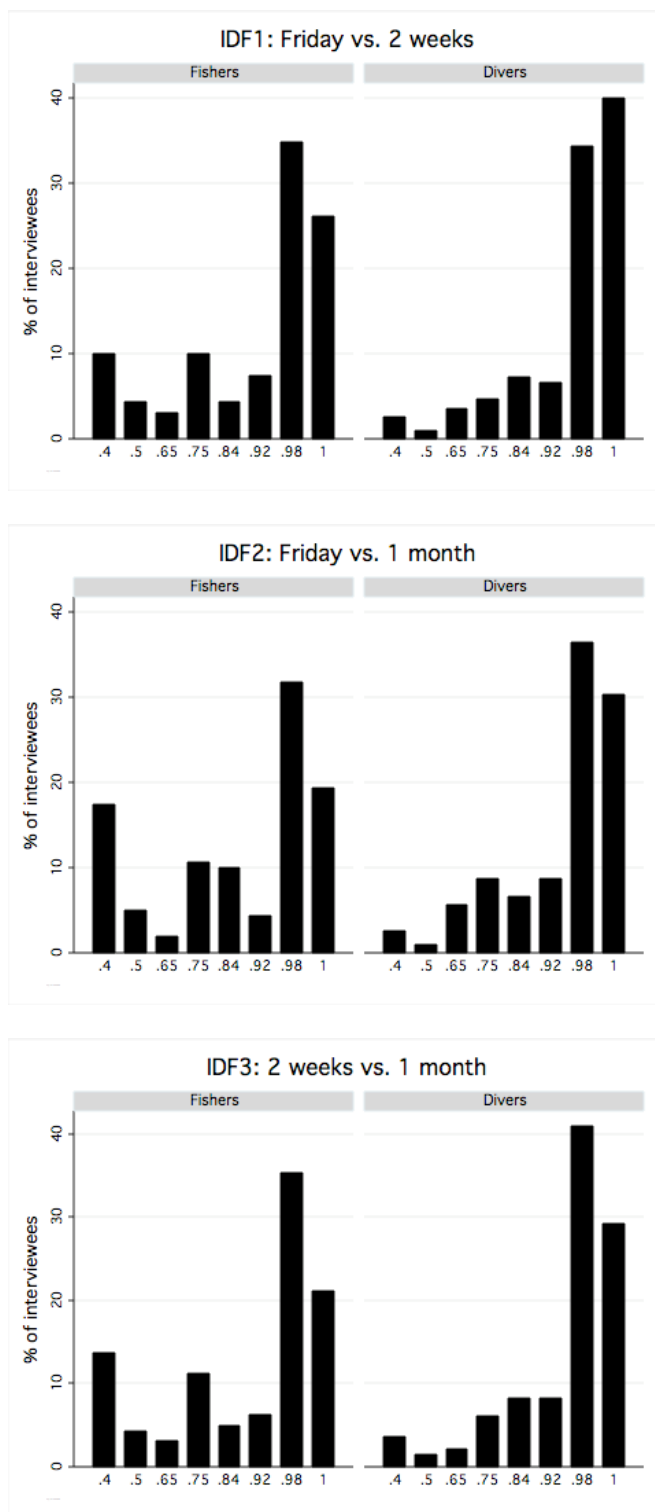
Table 6.4. Mean, with standard error in parentheses, gear scores, reserve scores, and conservation scores for interviewed fishers and divers.

	Gear Score	Reserve Score	Conservation Score
Fishers	53.6 (1.7)	36.2 (2.7)	46.5 (1.4)
Divers	75.0 (1.6)	69.4 (1.5)	72.5 (1.1)

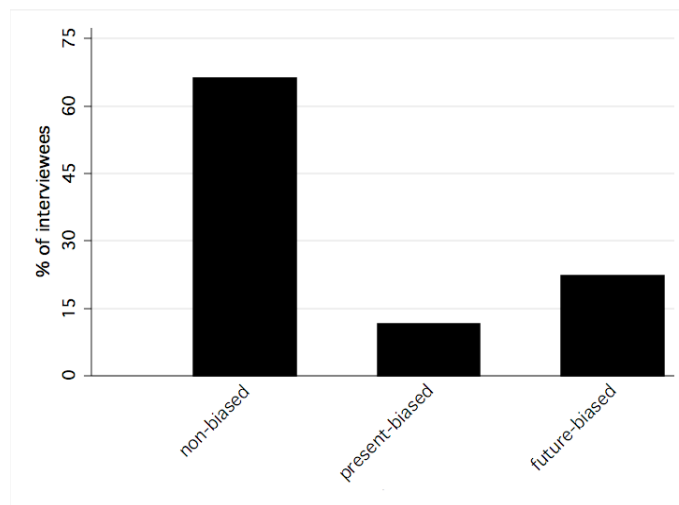
Graph 6.1. Cumulative distributions of individual discount factors (IDFs) as elicited from three price lists with different pairs of payment dates. Solid line represents fishers and dashed line represent divers.



Graph 6.2. Distributions of individual discount factors (IDFs) for fishers and divers as elicited from three price lists with different pairs of payment dates.



Graph 6.3. Distributions of bias among fishers and divers as determined by the relationship between IDF_1 and IDF_3 . Does not include interviewees with multiple switching points within a price list. Inter-profession and inter-island differences not significant.



Appendix A: Time Preference Survey

Survey Instructions:

This last part of the survey will only take a few minutes. For completing these last few survey questions, you will receive up to fl. 50. All you have to do is choose how you would like to be paid: sooner or later. There are 21 questions; each is a choice between a sooner payment and a later payment. After you answer all of the questions, you will draw a chip from this bag. The chips are numbered from 1 to 21 corresponding to the numbers of the questions. You will be paid according to your choice in the question whose number is on the chip. For example, if you choose the chip with number 7 on it, you will receive the amount of money you chose in response to question 7 on the date mentioned in that question. Payments will be available for pick up on Fridays between 1pm and 5pm. I will personally be there to give you your payment. Would you like to participate in this part of the interview?

Survey Questions:

This Friday vs. 2 weeks from this Friday?

1. Would you like to receive fl. 50 this coming Friday or fl. 50 2 weeks from this coming Friday?
2. Would you like to receive fl. 48 this coming Friday or fl. 50 2 weeks from this coming Friday?
3. Would you like to receive fl. 44 this coming Friday or fl. 50 2 weeks from this coming Friday?
4. Would you like to receive fl. 40 this coming Friday or fl. 50 2 weeks from this coming Friday?
5. Would you like to receive fl. 35 this coming Friday or fl. 50 2 weeks from this coming Friday?
6. Would you like to receive fl. 30 this coming Friday or fl. 50 2 weeks from this coming Friday?
7. Would you like to receive fl. 20 this coming Friday or fl. 50 2 weeks from this coming Friday?

This Friday vs. 4 weeks from this Friday?

8. Would you like to receive fl. 50 this coming Friday or fl. 50 1 month from this coming Friday?
9. Would you like to receive fl. 48 this coming Friday or fl. 50 1 month from this coming Friday?
10. Would you like to receive fl. 44 this coming Friday or fl. 50 1 month from this coming Friday?
11. Would you like to receive fl. 40 this coming Friday or fl. 50 1 month from this coming Friday?
12. Would you like to receive fl. 35 this coming Friday or fl. 50 1 month from this coming Friday?
13. Would you like to receive fl. 30 this coming Friday or fl. 50 1 month from this coming Friday?
14. Would you like to receive fl. 20 this coming Friday or fl. 50 1 month from this coming Friday?

Two weeks from Friday vs. 4 weeks from this Friday?

15. Would you like to receive fl. 50 2 weeks from this coming Friday or fl. 50 1 month from Friday?
16. Would you like to receive fl. 48 2 weeks from this coming Friday or fl. 50 1 month from Friday?
17. Would you like to receive fl. 44 2 weeks from this coming Friday or fl. 50 1 month from Friday?
18. Would you like to receive fl. 40 2 weeks from this coming Friday or fl. 50 1 month from Friday?
19. Would you like to receive fl. 35 2 weeks from this coming Friday or fl. 50 1 month from Friday?
20. Would you like to receive fl. 30 2 weeks from this coming Friday or fl. 50 1 month from Friday?
21. Would you like to receive fl. 20 2 weeks from this coming Friday or fl. 50 1 month from Friday?

Do you have a bank account?

Do you have a credit card?

Do you have a friend who would loan you fl. 50?

How much interest would they charge you?

Appendix B. Survey questions about management of coral reef resources**Gear Questions:**

1. Should there be a limit to how small the mesh size can be on a trap?
2. Should rectangular holes be required in the side of fish traps to let small fish escape?
3. Should there be a limit how small mesh size can be on seine?
4. Should there be a limit how small mesh size can be on gill net?
5. Should trap fishing be banned?
6. Should snorkel fishing be banned?
7. Should fishing with seines be banned?
8. Should gill net fishing on reefs be banned?
9. Should gill net fishing everywhere around the island be banned?

Reserve Questions

1. Do you support no fishing areas?
2. Do you think there should be more and/or larger no fishing areas?
3. Do you think there should be areas temporarily closed to fishing?
4. Should fishing on the reefs be banned?
5. Do you support no diving areas?
6. Do you think there should be more and/or larger no diving areas?
7. Do you think there should be areas temporarily closed to diving?

Miscellaneous Management Questions:

1. Should there be a limit to the number of fishermen allowed to fish?
2. Should there be a limit to the number of divers allowed to dive?
3. Should catching juveniles be banned?
4. Should uncontrolled anchoring be banned if the government provided more buoys?
5. Are there any species you think should no longer be fished?

References

- Akapalu, W. (2008) Fishing regulations, individual discount rate, and fisherman behaviour in a developing country fishery. *Environment and Development Economics* **13**, 591-606.
- Bernard, H.R. (1994) *Research methods in anthropology: Qualitative and quantitative approaches*. Sage Publications, Thousand Oaks, CA, p. 585.
- Bockstael, N.E., Opaluck, J.J. (1983) Discrete modelling of supply response under uncertainty: The case of the fishery. *Journal of Environmental Economics and Management* **10**, 125-137.
- Bowles, S. (1998) Endogenous preferences: The cultural consequences of markets and other economic institutions. *Journal of Economic Literature* **26**.
- Cardenas, J.C., Carpenter, J. (2008) Behavioural development economics: Lessons from field labs in the developing world. *Journal of Development Economics* **44**, 311-338.
- Carson, R.T., Roth Tran, B. (2009) Discounting behavior and environmental economics. *Journal of Neuroscience, Psychology, and Economics* **2**, 112-130.
- Coller, M., Williams, M.B. (1999) Eliciting individual discount rates. *Experimental Economics* **2**, 107-127.
- Curtis, J. (2002) Estimates of fishermen's personal discount rate. *Applied Economics Letters* **9**, 775-778.
- Eggert, H., Lokina, R.B. (2007) Small-scale fishermen and risk preferences. *Marine Resource Economics* **22**, 49-67.
- Eggert, H., Martinsson, P. (2004) Are commercial fishers risk-lovers? *Land Economics* **80**, 550-560.
- Eggert, H., Tveteras, R. (2004) Stochastic production and heterogeneous risk preferences: Commercial fishers' gear choices. *American Journal of Agricultural Economics* **86**, 199-212.
- Frederick, S., Loewenstein, G., O'Donoghue, T. (2002) Time discounting and time preference: A critical review. *Journal of Economic Literature* **XL**, 351-401.
- Grafton, R.Q., Kompas, T., Lindenmayer, D. (2005) Marine reserves with ecological uncertainty. *Bulletin of Mathematical Biology* **67**, 957-971.
- Hardisty, D.J., Weber, E.U. (2009) Discounting future green: Money versus the environment. *Journal of Experimental Psychology: General* **138**, 329-340.
- Hughes, T.P. (1994) Catastrophes, phase-shifts, and large-scale degradation of a Caribbean coral reef. *Science* **265**, 1547-1551.

- Knowlton, N. (2004) Multiple “stable” states and the conservation of marine ecosystems. *Progress In Oceanography* **60**, 387-396.
- Levitt, S.D., List, J.A. (2007) What do laboratory experiments measuring social preferences reveal about the real world? *Journal of Economic Perspectives* **21**, 153-174.
- Mistiaen, J.A., Strand, I.E. (2000) Location choice of commercial fishermen with heterogeneous risk preferences. *American Journal of Agricultural Economics* **82**, 1184-1190.
- Munro, G.R., Scott, A.D. (1985) The economics of fisheries management. In: *Handbook of Natural Resource and Energy Economics*. Vol. II. (Eds. A.V. Kneese, J.L. Sweeney), Elsevier Science Publishers.
- Opaluck, J.J., Bockstael, N.E. (1984) Behavioral Modeling and Fisheries Management. *Marine Resource Economics* **1**, 105-115.
- Pauly, D. (2006) Major trends in small-scale marine fisheries, with emphasis on developing countries, and some implications for the social sciences. *Maritime Studies* **4**, 7-22.
- Sadovy, Y. (2006) Trouble on the reef: the imperative for managing vulnerable and valuable fisheries. *Fish and Fisheries* **6**, 167-185.
- Sanchirico, J.N., Malvadkar, U., Hastings, A., Wilen, J.E. (2006) When are no-take zones an economically optimal fishery management strategy? In: *Ecol Appl*. Vol. 16. pp. 1643-1659.
- Smith, M.D., Wilen, J.E. (2005) Heterogeneous and correlated risk preferences in commercial fishermen: *The Perfect Storm* dilemma. *The Journal of Risk and Uncertainty* **31**, 53-71.
- Sumaila, U.R. (2004) Intergenerational cost-benefit analysis and marine ecosystem restoration *Fish and Fisheries* **5**, 329-343.

CHAPTER 7:
A socioeconomically informed approach to managing
fishing and diving on Caribbean coral reefs

Abstract

The coral reef ecosystems of Curaçao and Bonaire are substantially degraded relative to their historical conditions. These islands have strong fishing traditions, and economies increasingly dependent on dive tourism. Bonaire has a marine park and limited measures in place to protect the nearshore marine resources; marine activities on Curaçao remain nearly unrestricted. Both islands should substantially augment their reef management in order to prevent further resource degradation and loss of the associated ecosystem services. Based on extensive socioeconomic interviews with fishers and professional SCUBA divers, this chapter presents the management preferences of these key stakeholders. Following this identification of socially-palatable management options, with a focus on gear and area restrictions, I discuss economic and socio-cultural drivers of fisher and diver behavior, and recommend four principles with which to frame a more sustainable management structure: effort and capacity reduction, gear-based management, marine reserves, and simplicity and enforceability. Within this, specific steps that should be taken in order to support long-term sustainable use of the coral reefs, including: cap the numbers of fishers, divers, and dive shops; reduce in latent fishing capacity via boat buyouts; transition to hook-and-line fishing only and ban gill net use immediately; establish large no-fishing and no-diving zones; enact simple and easily enforceable regulations with few caveats. While these measures may seem draconian, they are necessary to safeguard fishing and diving as important sources of employment and leisure.

Keywords: artisanal fisheries, fisheries management, SCUBA diving, sustainable use, coral reefs, marine reserves, gear-based management

Introduction

The reefs of Curaçao and Bonaire are reasonably healthy by modern Caribbean standards, but considerably degraded from their pristine states (see Chapter 5). That these reefs are not in worse condition can largely be attributed to historical artifact, not to comprehensive regulations and strong enforcement. There are no limits on the number of people who can fish or dive on either island, nor are there limits on the quantity or species of fish that can be caught. The fishery resources of Curaçao and Bonaire are not currently being managed for long-term sustainable catches. Tourism, including dive tourism, continues to grow. Coastal development proceeds at a rapid pace. Relatively low fishing pressure (under 200 fishers on Curaçao and under 100 on Bonaire), limited use of destructive fishing techniques (i.e., gill net use not widespread until recently, virtually no fishing with explosives), and a geographic location south of the hurricane belt have staved off some ecosystem degradation. However, population growth, economic development, and climate change are increasing the pressures on these reefs. The luck and the time to act are running out.

To protect the coral reef ecosystems of these islands, comprehensive management plans are needed, plans that account for all the factors mentioned above. A truly holistic planning approach would also include discussion of likely climate change impacts and would integrate consideration of terrestrial activities, but here I focus simply on how to best manage fishing and SCUBA diving. I start by describing the marine management structures currently in place on each island, and then present the results of a socioeconomic survey I administered to fishers and professional divers on both islands. Survey results include the types of fishing gears that are used, the elasticity of fishing effort in response to changes in fuel and fish prices, the perceived profitability of working as a fisher or diver, and the support for various management measures, with a focus on gear and area restrictions. Based on these data, along with results presented in previous chapters, and my interactions with each of the 388 individuals I interviewed, I present

(1) management actions that would receive stakeholder support, and (2) options for a more aggressive management approach that would be less popular, but more likely lead to effective ecosystem conservation, and potentially to ecosystem restoration.

Current regulatory structures

There is a large difference between how marine resources are managed on Curaçao versus on Bonaire. Bonaire has more regulations in place than does Curaçao that are designed to protect the fish populations and coral reefs. The inshore waters of the entire island of Bonaire, from the high-water line to 60 meters depth, were designated as a marine park in 1979; this is managed by Stichting Nationale Parken Bonaire (STINAPA). An array of activities are restricted within the park (Alliance, 1991). Dumping of biological or chemical substances that might damage the environment is prohibited. Anchoring is prohibited, although boats under 12 feet may use a stone anchor. A permit is required to remove mangroves, although there is an exception for traditional use.

Bonaire's fishing regulations prohibit spearfishing, the catch of turtles or the collection of their eggs, and the catch of gravid female lobsters or lobsters under 25 cm total length. A permit is required to collect conch or to undertake construction (e.g. piers) in the park, and fishing nets must have a minimum mesh size of 3 cm on the upper two-fifths of the net and 2 cm on the lower three-fifths. Only traditional fishing methods (i.e. lines, rods, casting nets, beach seines, and fish traps) are permitted, although gill nets are not explicitly banned. Two small no-fishing zones were established within the park in 2007. Bottom fishing, anchoring (even small boats with stones), and the use of fish traps are prohibited in the no-fishing zones, although collection of three species of bait fish is permitted.

To dive on Bonaire, one must pay an annual nature fee (US\$ 25 for SCUBA divers and US\$ 10 for non-divers) and obtain a tag to use the marine park. To procure a dive tag, divers

must attend an orientation and complete a check-out dive. It is prohibited to collect or touch anything underwater, to wear gloves, or to use chemical light sticks. In 1991, two small no-diving zones were established. The maximum punishment per offense for violating any of Bonaire's marine park laws is US\$ 5,000 and one month of imprisonment.

On Curaçao, spearfishing is prohibited, although the ban is less well enforced than on Bonaire, as are catch of turtles and collection of their eggs, and collection of corals. Apart from those few restrictions, fishing can occur anywhere at anytime, and any quantity of any species can be caught using any type of gear.

Curaçao has an Underwater Park that was established in 1983 and is located on the southeastern portion of the island; however, it remains a "paper park" within which fishing and diving of all kinds occur. A dive tag system was established on Curaçao in the 1990s, but it was short-lived due to corruption. A marine park ordinance has been proposed which would create a marine park surrounding Curaçao from the high-water line out to 300 meters from the coast. Such a designation would enable Curaçao to begin charging an access fee as is done on Bonaire. There is also a proposed fisheries ordinance, which would restrict the use of gill nets and fish traps, among other measures. Both draft ordinances have existed in some form for over a decade without amassing the political support necessary to pass them into law.

Fish and reef health: perceptions and reality

There is a long history of marine science research on both islands, organized in part by the foundation for Caribbean Research and Management of Biodiversity (CARMABI), which has operated on Curaçao since the mid-1950s. However, long-term fish and benthic data sets are sparse, with the notable exception of corals on Curaçao (Bak et al., 2005). Regardless, it is clear that the coral reef ecosystems of both islands have substantially degraded over the last half century. (See Chapter 5 for a summary of the available data.) Fishers are more acutely aware of

these declines in fish populations than divers. The majority of fishers have perceived a large decline in fish catches in recent years (see Graph 5.1a). Divers also perceive a decline, but still consider the fish populations to be abundant and the reefs to be healthy (see Graph 5.1b). Fishers tend to consider external factors, such as pollution and changes in climate and currents, to be responsible for the decline, whereas divers consider local factors such as fishing and coastal development the primary causes (see Graph 5.6).

Within this context of degraded marine ecosystems and divergent perceptions of natural resource health, I conducted extensive socioeconomic stakeholder interviews to better understand which marine activities are currently occurring, and to elicit opinions on what the appropriate measures are for managing use of the nearshore environment.

Methods

I interviewed 126 fishermen on Curaçao, 51 fishermen on Bonaire, 112 professional SCUBA divers on Curaçao and 99 professional SCUBA divers on Bonaire. (See Chapter 5 for detailed interview methods.) Interviewees were questioned about which management measures they supported. χ^2 tests were used to compare gear usage between islands, and to compare support for regulatory measures between islands and professions.

Results

More or less management

The majority of interviewees believed there should be more management of fishing (Graph 7.1a). Significantly more fishers and divers on Curaçao (79% and 94%, respectively) had this viewpoint than their counterparts on Bonaire (51% and 64%, respectively, both $p < 0.002$). The majority of interviewees also believed there should be more management of diving (Graph 7.1b). A significantly greater portion of divers on Curaçao than Bonaire (89% and 60%,

respectively) ascribed to this view ($p < 0.001$), and there was no significant inter-island difference in fishers' responses. Notably, few interviewees indicated that overall there was too much management and that it should be reduced. The exception to this was the 15% of fishers on Bonaire who believed there should be less management of fishing.

Gear usage

Most fishers use multiple types of fishing gear. Hook-and-line bottom fishing and trolling were by far the most common fishing techniques, used by 93% and 90% of interviewed fishers, respectively (Graph 7.2). Other gears used include snorkel (i.e. hook-and-line fishing where specific individual fish are targeted by fishers swimming and wearing a snorkel and mask, 20%) beach seines (13%), gill nets (10%), spearguns (9%), and fish traps (7%). There are significant differences in gear use between Curaçao and Bonaire. There is a greater proportion of snorkel fishers on Bonaire than Curaçao ($p = 0.001$). A greater proportion of fishers on Curaçao than Bonaire use spearguns and beach seines (both $p < 0.025$). Also notable is that greater than 20% of interviewed fishers on both islands formerly used fish traps, but current usage is at less than 10% of fishers on each island. Gill nets are the least commonly used type of gear on both islands.

Elasticity of fishing behavior

Fishers were asked how their fishing behavior changed in the past when fuel price increased, and how they would change their fishing behavior in the future if fuel or fish prices increase further (Graph 7.3). Previous increases in fuel price induced 37% of fishers to change the type of gear they use, 30% to change the species they targeted, 41% to stay closer to port, 9% to fish for more hours, and 26% to fish for fewer hours. Among fishers who responded that their behaviors have changed, the majority elaborated that they had shifted from trolling to

bottom fishing with a commensurate switch from targeting pelagic species such as wahoo (*Acanthocybium solandri*), dorado (*Coryphaena hippurus*, also called mahi mahi), and tunas (*Thunnus spp.*), to targeting deep reef snappers (Lutjanidae) and groupers (Serranidae). Significantly more fishers on Bonaire than on Curaçao reported having changed their gear type and their target species when fuel price increased previously (both $p < 0.02$).

A future increase in fuel price would induce 30% of fishers to change the type of gear they use, 27% to change the species they targeted, 38% to stay closer to port, 14% to fish for more hours, and 30% to fish for fewer hours. Again, this is largely a shift from trolling for pelagic fish to bottom fishing for snappers and groupers. Significantly more fishers on Curaçao than Bonaire reported that a future fuel price increase would increase or decrease the number of hours they fished ($p < 0.022$).

In response to a future increase in the price for which they could sell their fish, 16% of fishers said they would change the type of gear they used, 17% would change the species they target, 27% would fish for more hours, and 2% would fish for fewer hours. Some fishers reported they would shift to primarily trolling for pelagic species, and others reported they would switch to primarily bottom fishing for snappers. There were no significant inter-island differences in these responses.

Divers were not posed questions about the elasticity of their diving practices.

Perceived profitability

Fifty-three percent of fishers considered fishing to be profitable, significantly more than the 44% of divers who considered diving profitable ($p = 0.075$, Graph 7.4). Those who consider their profession profitable were asked how many years into the future they expected it would continue to be profitable (Graph 7.5). The distribution of responses was significantly different between professions, with more fishers than divers responding that their respective profession

will be profitable indefinitely, and also more fishers than divers responding that their profession will be profitable for five or fewer additional years ($p = 0.037$). Fishers on Curaçao were significantly more likely than those on Bonaire to believe that fishing would continue to be profitable indefinitely ($p = 0.046$). Inter-island differences in divers' responses were not significant.

Gear restrictions

Among fishers, gear modifications were more popular than gear bans (Graph 7.6a). Requiring minimum mesh sizes for gill nets, beach seines, and fish traps received 85%, 79%, and 76% support from fishers, respectively, and 83% of fishers supported requiring the use of escape gaps in fish traps. Banning traps and beach seines were the least popular gear restrictions, and those received significantly less support from fishers on Curaçao than on Bonaire (both $p < 0.005$). A ban of gill net use received the most support of any gear ban, at 47% of fishers, and a ban of gill net use on the coral reefs was the only gear ban supported by the majority of fishers (64%).

Significantly more divers than fishers supported all of the gear restrictions inquired about in the interviews (all $p < 0.05$). A majority of divers supported every gear restriction. Just as with fishers, gear modifications were generally more popular among divers than gear bans (Graph 7.6b), with the exception of banning gill net use on the reefs, which garnered support from 98% of divers. All of the gear modifications received support from greater than 90% of divers. Gill nets were the most supported ban (78%) followed by fish traps (64%) and beach seines (53%), and all bans received significantly greater support from divers on Bonaire than on Curaçao (all $p < 0.05$). On Bonaire, 14% of fishers and 55% of divers supported a ban on snorkel fishing. That question was a late addition to the survey and was not posed to interviewees on Curaçao.

Area restrictions

Divers were more supportive than fishers of every area restriction about which I inquired ($p < 0.05$, Graph 7.7). A ban of fishing on the reefs was supported by 73% of divers (inter-island difference not significant). Fishers were much less supportive of that measure, with 26% of fishers on Bonaire and 11% on Curaçao offering support (significant inter-island difference, $p = 0.017$).

A greater proportion of fishers on Bonaire (62%) supported their existing no-fishing areas than the proportion of fishers on Curaçao (30%) who supported the designation of no-fishing areas ($p < 0.001$). This trend holds for divers, with 97% of divers on Bonaire supporting the existing no-fishing areas, and significantly less support for the designation of no-fishing areas on Curaçao (82%, $p < 0.001$). On Bonaire, 35% of fishers and 62% of divers supported the designation of new no-fishing areas in addition to those that currently exist.

As for no-diving areas, those that exist on Bonaire were supported by 91% of fishers and 97% of divers. In contrast, only 32% of divers on Curaçao supported the creation of no-diving areas. Fishers on Curaçao were not asked about permanent or temporary no-diving areas as those questions were a late addition to the survey. Designation of additional no-diving areas received 71% support from Bonaire's fishers and 49% from the divers. Overall, temporary closures of areas to diving received support from 55% of divers and 90% of fishers on Bonaire, and from 81% of divers on Curaçao.

Effort restrictions

A greater number of divers than fishers supported limits on the number of fishers and on the number of divers (both $p < 0.001$, Graph 7.8). Only 2% of fishers supported the idea of limiting the number of people allowed to fish. Significantly more fishers and divers on Bonaire than Curaçao supported limiting the number of SCUBA divers ($p = 0.003$).

Eleven percent of fishers believed that their fishing damages the reefs. Ninety-four percent of divers believed diving damages the reefs. There were no significant inter-island differences between fishers or divers responses.

Ninety-one percent of all interviewees support prohibiting the catch of juveniles, which is more support than any other measure in the survey received (Graph 7.8). Significantly more divers than fishers supported this prohibition ($p = 0.007$), and there were no significant inter-island differences.

Anchoring

More divers than fishers, 97% versus 67%, believed that anchoring damages the reefs ($p < 0.001$, Graph 7.8), with no significant inter-island differences in the responses of fishers or divers. The majority of fishers and divers indicated they would support a complete ban on anchoring if the government provided more buoys, with significantly more support for this measure among divers than fishers ($p < 0.001$). Among divers, those on Curaçao were significantly more in favor of a prohibition on anchoring ($p = 0.011$).

Marine Park Fee

Ninety-six percent of divers on Bonaire support the fee that is charged for diving there, and 94% of divers on Curaçao would support having such a fee on Curaçao (Graph 7.8). However, many interviewees noted the need for transparency and accountability in the use of the money collected in fees. This question was not asked of fishers.

Discussion

To distill the implications of this information on stakeholder preferences, I will first summarize which measures have the greatest support, then discuss some of the potential drivers of fishing and diving behavior, and finally offer management recommendations.

If the majority ruled

The majority of fishers and divers on both islands perceive a need for additional management of fishing and diving. Over 70% of both fishers and divers support (1) requiring a minimum mesh size for traps, gill nets, and beach seines, (2) requiring escape gaps in fish traps, and (3) banning the catch of juveniles. Over 70% of divers and the slim minority of fishers support a ban on gill nets. There is over 50% support from both fishers and divers for a ban on anchoring, establishment of temporary no-fishing zones, and a ban of gill net fishing on the reefs.

Fisher and diver responses to questions about area restrictions were more divergent. The no-diving and no-fishing areas that exist on Bonaire are well supported by both fishers and divers there, but support for establishing similar areas on Curaçao is significantly weaker. Similarly, additional permanent no-fishing and no-diving areas on Bonaire received less support than temporarily closing areas to these uses. A ban of fishing on the reefs is markedly more popular with divers than fishers.

Fishers and divers on Curaçao see a greater need for additional management than those on Bonaire. This is not surprising given the comparative lack of regulations on Curaçao. However, beyond this general desire for management, individuals on Curaçao are overall less supportive of specific management measures than their counterparts on Bonaire, which may somewhat complicate attempts to capitalize on this consensus.

Focusing on these well-supported restrictions would be a logical first step. This is not to say that such an approach would not meet with resistance. In general, fishermen with an anti-regulation bent seem to often wield great political influence despite their dwindling numbers, perhaps a symptom of societal nostalgia for simpler times. Curaçao and Bonaire are no exception to this rule. Nevertheless, the breadth of the common ground between fishers and divers on measures that should be implemented is promising.

Divers of fishing and diving behavior

More fishers than divers believe that their profession is profitable and will continue to be so indefinitely. This optimism from over half of interviewed fishers about fishery profitability is at odds with fishers' overall perspective that fish populations are depleted and declining (see Chapter 5). However, in a somewhat bipolar distribution, fishers were also more likely than divers to think their profession will be profitable for five or fewer years. More importantly, only approximately half of the interviewed fishers and divers believe their respective professions are even profitable currently. Even though employment options on these islands are limited, this is an indication that selection of these professions is not a purely financial decision.

Preference, perhaps more so than profitability, plays a large role in the career decisions of fishers and divers. The decision to fish or dive is often a lifestyle choice, a passion cum profession. Fishers and divers are often not sustained solely by their incomes associated these professions, rather they also rely upon supplementary income sources (e.g., fishers commonly work in construction and divers often live partly off their savings) in order to subsidize a fishing or diving lifestyle. A subsidy to these professions is also often provided in the form of family members who cover some portion of the living expenses.

There are cultural aspects of fishing, and lifestyle aspects of both professions, that entice individuals to pursue them. The average fisher has three generations of fishers in his family and has been fishing since the age of thirteen. While divers do not share that personal or family career longevity, many have in common the desire for an adventurous outdoor lifestyle. Fishers also conveyed to me the great value they place on the freedom of not having a boss.

Within the context of these non-financial motivators for profession selection, it is interesting to consider how further changes to profitability might affect fishing behavior. High fuel price tends to reduce the hours fished and keep fishers closer to shore spending more time

bottom fishing, as opposed to offshore trolling for pelagic species. In this way, conserving fuel may increase pressure on reef fish populations, and although most fishers say they would continue to fish in the same manner, or reduce their fishing hours as the price of fuel increases, 14% report that they would increase their fishing effort. This anticipated increase in fishing effort is more pronounced as a response to increased fish price.

Other factors that might influence the decision to continue working as a fisher or diver include sunk costs (i.e., investment in a boat, gear, or training), an intuitive calculation of marginal costs and benefits, the relative value of other employment options, the market value of fish, the last time they (or another fisherman) made a high-value catch, or even the income of significant others or family members with whom they share expenses. The results of these interviews cannot tease apart these factors, but the key point here is that career decisions are complex, and profitability is often only one of the contributing factors. Therefore, it is important to consider socio-cultural context in designing management.

Management recommendations

The decentralized and diverse nature of these small-scale fisheries poses a management challenge; many species are harvested, many gear types are used, and many boats land their catches in many ports. Notably, Curaçao and Bonaire do not have a tradition of customary fisheries restrictions, such as taboo areas or species, upon which a new management framework can be constructed. In this regard, management of artisanal fisheries in the Caribbean is quite different than on Pacific Islands where there is a long history of community-based management (Cinner and Aswani, 2007). However, perhaps a commitment to a new regime focused on sustainable management could foster the creation of a tradition.

In this context, the management recommendations I offer aim to increase reef fish populations and protect coral reef habitat, while minimizing socio-cultural disruption. While

following these recommendations will require substantial changes in the near-term to the way the reefs are used, they are put forth with the overarching goal of sustaining both the fishing and diving sectors in the long term. Recommendations fall under four principles: (1) effort and capacity reduction, (2) gear-based management, (3) marine reserves, and (4) simplicity and enforcement.

1. Reduce fishing and diving

Reductions in fishing effort and diving intensity are necessary. The number of fishers on both islands should be capped. While the current numbers of fishers on Curaçao and Bonaire may seem low, it is not low in relation to the current number of fish. Furthermore, a low density of fishers using traditional fishing gear can easily deplete a reef (see introduction to Chapter 5 for discussion of this point). Simply put, fishers are capable of catching fish more quickly than fish can grow and reproduce. Creating a cap on the number of fishers would be difficult politically considering that measure garnered only 2% support from interviewed fishers, making it the least popular of all the measures about which I inquired. However, this could be facilitated through monetary payments to fishers who agree to stop fishing, similar to government payments to farmers for keeping land fallow or placing it into a land trust. It is important to note here that there is very little subsistence fishing on Curaçao and Bonaire, so restrictions it would not pose a food security issue. In fact, most of the food consumed on these islands, including the fish (Bruckner and Bruckner, 2003), is imported. If a cap were pursued, this lack of nutritional dependence on fishing might alleviate some of the social resistance that can reasonably stem from the concern that limiting fishing effort impedes the ability of poor people to feed themselves and their families.

Young people should receive training in alternative careers to fishing. The dearth of young people interested in pursuing a career in fishing, whether due to a perceived lack of

profitability and/or to a lack of allure of the fishing lifestyle, should be capitalized upon. For example, training the younger generation for high-tech employment could prevent future increases in the number of fishers. This could be part of a longer-term program to reduce fishing effort to levels that would allow fish populations to recover from the last century of exploitation.

Latent fishing capacity should be reduced. Fishing is often used as an interim or supplementary source of income for the unemployed and underemployed. Ensuring other employment opportunities for those who do not desire careers as fishers could alleviate potential increases in fishing effort corresponding with economic downturns. As of 2002 there were 435 boats in Curaçao, although only 111 of them were active (Dilrosun, 2002). The great number of available boats and the presence of many part-time and former fishermen indicate the potential for a substantial increase in fishing effort. In response to changing market forces, fishing could dramatically and immediately increase. One approach to reducing latent capacity is to purchase and decommission fishing boats. Such buyouts have been employed in industrial fisheries around the world to reduce fishing capacity (Groves and Squires, 2007), and could possibly be successful here – many boat owners might be willing to exchange their boats for cash. However, maintaining a lower number of vessels would require a cap on the total number of boats, and the establishment of a permit system or some means for monitoring the remaining vessels.

Fishing by non-residents should be prohibited. There are very few sportfishing businesses (approximately three on Bonaire and five on Curaçao) catering to tourists interested in recreational fishing, so such a ban would have quite limited economic impact. Conferring an exclusive fishing right to local fishers would likely garner good will from the community and facilitate negotiations on other measures to improve fishery sustainability. Although surmountable, defining who is local and who is not would prove challenging given the

substantial numbers of recent South American and Asian immigrants and Dutch and American part-time residents.

The number of divers should be capped. While the effects of diving on fish populations are less direct, they can still be formidable. Bonaire received 35,000 dive tourists last year, and the odds are that each one of them made physical contact with the reef collectively causing significant ecological damage (Tratalos and Austin, 2001). As 94% of interviewed divers acknowledged, diving damages coral reefs. Such damage eventually reduces habitat provided by a reef's three-dimensional structure, and thereby reduces the carrying capacity of a reef for fish (Wilson et al., 2010). Interviewees frequently commented that recreational divers with underwater cameras caused the most damage to the reef because their buoyancy control was not refined enough to enable them to photograph the reef without making physical contact with it. Requirement of an advanced certification or a minimum number of logged dives, or a special checkout dive with a camera in order to be granted the right to use a camera might be supported by the professional diving community. However, enforcement of such measures could be somewhat laborious – especially given the large portion of unguided shore diving on these islands. Although Bonaire requires a check-out dive for recreational divers, that dive is usually unsupervised and it is a missed opportunity for evaluation and improvement of recreational divers' buoyancy control.

The dive tag fee should be increased to US\$ 50 and charged to all tourists (including cruise ship tourists who are currently exempted) on both islands as a conservation fee. All tourists who visit the island impact its marine environment, whether or not they ever enter the water, via the infrastructure required to support them and the sewage they produce. Such a fee would still be reasonable given much higher fees elsewhere (e.g., US\$ 100 in park fee in the Galapagos and US\$ 20 per person per day on Great Barrier Reef), and could finance the buyouts of fishers and boats mentioned above, as well as the increased costs of monitoring and

enforcement associated with this suite of recommendations. The largest obstacle to the success of marine reserves is often funding, dive fees are often well below the level tourists are willing to pay, and the benefits of fees have been shown to outweigh the risk to the tourist industry of reduced visitors (Terk and Knowlton, 2010), making a fee increase an appropriate and important measure.

Increasing the opportunities for wreck diving should be explored. This is a somewhat less conventional approach to reducing diving pressure on the reefs (Wilhelmsson et al., 1998), but as one diver said to me, “every dive made on a wreck is a dive not made on the reef.” While there are certainly environmental effects associated with creating wrecks that would need to be mitigated (e.g. the chemical toxicity of vessels), the possibility merits consideration.

The number of dive shops should be capped. Professional divers noted that competition between the dive shops for business was often intense, resulting in small profit margins, so commensurate with a cap on the number of divers, there should be a cap on the number of dive shops at the current level. Currently, there are approximately 25 dive shops on Curaçao and 20 on Bonaire. Limiting the number of divers would allow a premium to be placed on diving on Curaçao and Bonaire, which could increase the profits of the dive industry.

Development should be restricted to projects already underway, as rooms for tourists is not currently a limitation. Pollution should be reduced and monitored, and tourist consumption of reef fish (e.g. catch-of-the-day in local restaurants) should be prohibited. These measures would be in the long-term best interest of a tourist industry based in large part on the presence of vibrant coral reefs.

2. Gear-based management

Fishing on Curaçao and Bonaire should transition to hook-and-line only. This would virtually eliminate the issues of bycatch and habitat damage associated with fishing and

(assuming some limit on fishing effort) it would give the fish population a chance to rebuild while having limited effects on fishers' incomes, since the vast majority of fishers already primarily use lines. Short of making this wholehearted transition, the types of fishing gear that are used should be regulated as a proxy for regulating the types of fish caught. This is often termed gear-based management (McClanahan and Mangi, 2004). Fishing can be problematic when it is either too selective (e.g. spearfishing eradicating large groupers) or not selective enough (e.g. gill nets). Gear-based management is also a means of addressing concerns about the fishing techniques used by recent immigrants from Asia and South America, namely gill net fishing, harvesting juveniles, and targeting herbivores. To an extent these types of restrictions could compensate for the potential political infeasibility of capping the number of fishers.

The speargun ban should be fully enforced on both islands. I interviewed fourteen fishers on Curaçao and two on Bonaire who reported that they currently use spearguns. Based on my discussions with those fishers, it is clear that there are additional fishers who continue to use spearguns in spite of the illegality. While the bycatch associated with spearfishing is negligible, the habitat damage (as described by the fishers themselves) is often quite high. The selective capture of large reef fish is problematic given their importance as sources of high quality and quantity larvae, their longer spawning season, their ability to teach younger individuals to migrate to spawning grounds, and their role in reducing the likelihood of trophic cascades (Birkeland and Dayton, 2005). These attributes of large fish suggest that a limit on snorkel fishing would also be warranted.

Use of fish traps should be phased out. They are no longer widely used and their high bycatch and habitat damage, and high catch of herbivorous parrotfish (Scaridae) and moray eels (Muranidae) is cause for concern (see Chapters 2 and 3). However, public support for a ban, especially among fishers, is low. There is nostalgia associated with trap fishing. Given this, at the very least, use of escape gaps should be required to reduce bycatch (Johnson, 2010).

Additionally, instead of an immediate ban, permits could be distributed to the few remaining fishers using traps. Trap fishing permits should be non-transferable, so that they become invalid once those fishers cease to fish. The maximum number of traps per fisher should be specified to avoid any future instance of increased fishing capacity. Most trap fishers use five or fewer traps, so five would be a reasonable maximum number. If a mechanism were in place to prevent new traps from entering the fishery, a buyout of traps currently in use could facilitate this phase out. Given that traps are frequently damaged by divers and require substantial maintenance, a buyout of traps might be well-received.

Beach seine use should be limited. Seines are a traditional type of fishing gear used primarily to harvest schools of bait fish. They are used in shallow waters and require three to ten fishers to set and monitor them. They are used infrequently – usually only when large schools of bigeye scad (*Selar crumenophthalmus*) are close to shore. Size restrictions, perhaps via mesh size regulation could be useful as fishers mention the nets are now being set around schools of small fish. There is very little support for banning seines due to strong cultural ties to this gear, but a cap-and-permit approach similar to that described for traps could be used for seines to ensure their use does not increase in the future. While a ban is unlikely, there is a general concern about the relationship between a reduction in bait fish and a reduction in the quantity of large pelagic fish entering the islands' shallow waters, and it might be possible to leverage that concern to further limit the use of seines.

Perhaps most importantly, gill nets should be banned as quickly as possible. They catch the few pelagic predators remaining on reefs, including sharks, which are now exceedingly rare on these reefs. They also cause habitat damage and have significant bycatch (see Chapter 4). Gill nets do not have the veneer of tradition, and are the least commonly used gear, the gear most disliked by divers, and the gear fishers most support banning. Steps should be taken to expedite the proposed ban.

3. *Marine reserves*

Large marine reserves should be established where fishing and diving are prohibited. Gear-based regulations can reduce catch of juveniles, reduce bycatch, and to some extent reduce the capture of large, old fish. However, even if both islands banned all gears except line fishing, there is no sure way to control which fish (e.g., rare species, juveniles, large and old individuals) take the bait. Marine reserves can provide a haven in which fish can grow old and multiply, and wherein the benthos can have a respite from photographing divers and stone anchor-throwing fishers. A complete ban of fishing on the shallow reefs did not receive much support from interviewees, but the establishment of no-fishing reserves did receive considerable support. There is greater support for the no-fishing and no-diving zones that currently exist on Bonaire than there is for the creation of equivalent new zones on Curaçao. This may just be wariness of the unknown, but fishers' support for no-fishing zones may also stem from the lack of clarity around whether the ecosystem benefits of such regulations will accrue to them in terms of larger catches in the future. If this is the case, measures to preventing tourist fishing and restricting diver access to the reefs could increase support for reserves among fishers.

As concerns no-fishing zones, grandfather in the grandfathers. There are a few old fishermen with small rowboats who have been displaced by the recently established no-fishing areas on Bonaire. Their boats have no engines, and they do not have cars with boat trailers, so there is nowhere else for them to fish. They fish infrequently and banning them from their traditional fishing area is simply bad public relations. Making an exception for these iconic community elders could be easily enforced as they could be readily identified from shore, and could send the important message that regulations can be reasonable and where possible yield to tradition. Although this conflicts with the philosophy of simple regulations outlined below, it could substantially increase community support for reserves.

I recommend each island protect 30% of the reefs in no-fishing/no-diving zones. This

percentage is likely large enough to produce ecologically meaningful conservation benefits without too deeply curtailing the fishing and diving industries. It also follows on the model of Australia's Great Barrier Reef Marine Park where reserves were expanded to cover 30% of the park after it became clear that the smaller set of reserves was inadequate for protecting the ecosystem. These reserves have shown benefits even in the first few years (McCook et al., 2010). The question of where to site these reserves will pose a formidable challenge, and in order to gain community support, the locations should be chosen via a transparent process that considers stakeholder preferences in a balanced way and objective way. While marine reserves are certainly not a panacea, especially for ocean-wide issues such as global warming and pollution (Allison et al., 1998), they do have the potential to locally prevent overfishing and habitat destruction, provide a refuge for biodiversity and a source of larvae for outside areas, and increase the biomass and abundance of fish within their boundaries (McClanahan and Graham, 2005, Gell and Roberts, 2003, Roberts et al., 2001, Lubchenco et al., 2003).

4. Simplicity and enforcement

Regulations should be designed for simplicity and ease of enforcement. Budgetary and personnel constraints limit the capacity for monitoring and enforcement on both Curaçao and Bonaire. High levels of voluntary compliance and social enforcement that might accompany clear rules where transgressions are conspicuous could reduce this enforcement burden. If there is a no-fishing area that completely bans fishing without any caveats or exceptions, then anyone seen fishing within those boundaries has broken the law. This is in contrast with the current no-fishing areas on Bonaire where bait fishing remains permitted. The boundaries of no-fishing and no-diving areas should be simple, correspond with geographic features and landmarks where possible, and be well advertized.

Simplicity and enforcement also complement each other as regards gear restrictions.

Whether the gear is gloves for divers, spearguns for fishers, or anchors for all boaters, enforcement of bans is simple and there can be no misunderstandings about how the law is applied. Making it illegal to even possess certain gears would be the most straightforward regulatory approach. Following the logic of this principle, I would not recommend promulgation of mesh size or fish size restrictions, nor would I recommend species restrictions or temporary closures. Catch quotas are perhaps the most resource intensive to enforce, making them the least appropriate for a multispecies artisanal fishery.

Beyond ease of enforcement, it is important for regulatory design to consider how much actual policing is required to ensure compliance. There need not be a park ranger at every dive shop and on every pier. Just as with speeding tickets for automobiles, the management question becomes how high the risk of apprehension must be to deter illegal behavior. Use should be made of previous research showing that to generate compliance, for fishers the risk of punishment is more important than the severity of the punishment (Akapalu, 2008). The regulatory overhaul I recommend would require robust monitoring and enforcement capacity on each island. This would be a non-negligible administrative burden, but worth the cost given the economic importance of healthy reefs to the viability of the fishing and diving industries.

Conclusion

While these recommendations were developed specifically for Curaçao and Bonaire, my hope is that they are somewhat universal. Finding truly universal solutions for sustainable management of coral reef fisheries is impossible. The specificities of each island are more than noise. There are however, some general guidelines. First, understand the distribution and intensity of current resource uses exerting pressures on the reefs. Second, understand the motivations and management preferences of the primary resource users. Third, identify common concerns between stakeholder groups and viable opportunities for legislating based

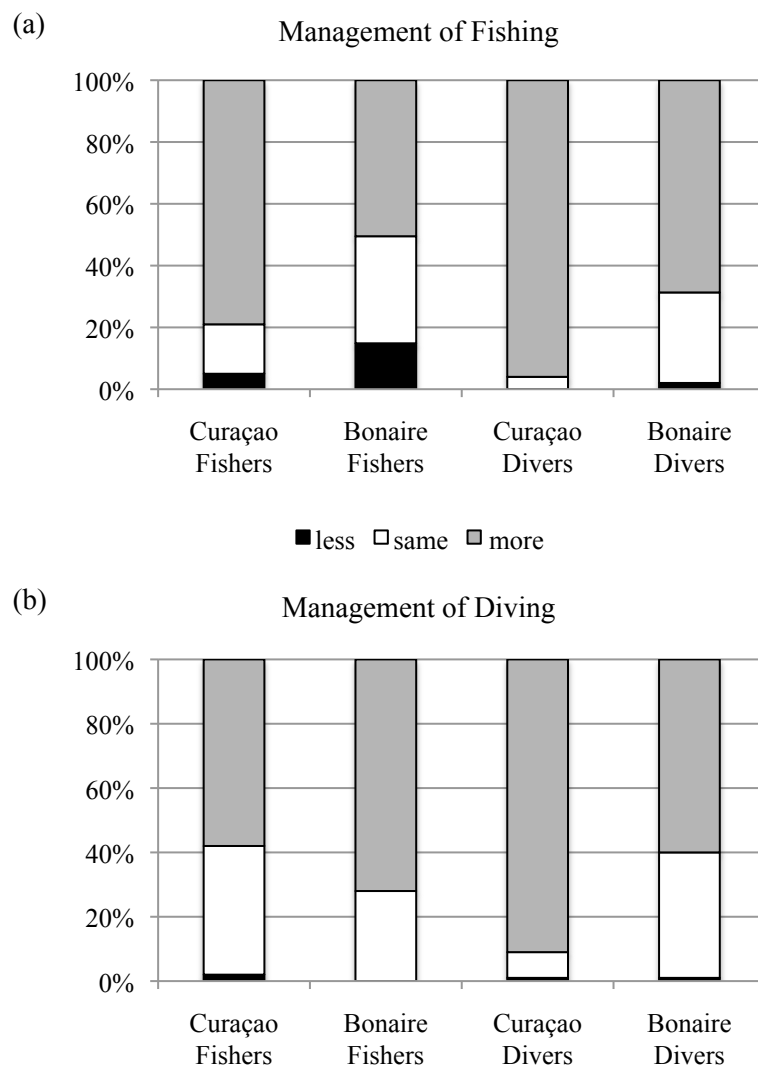
upon measures that have broad public support. Fourth, develop a comprehensive management plan that is sensitive to the socio-cultural context. A management plan to improve the sustainability of resource use should include effort and capacity reductions, gear-based management, and marine reserves, and should be simple and easily enforceable.

Acknowledgements

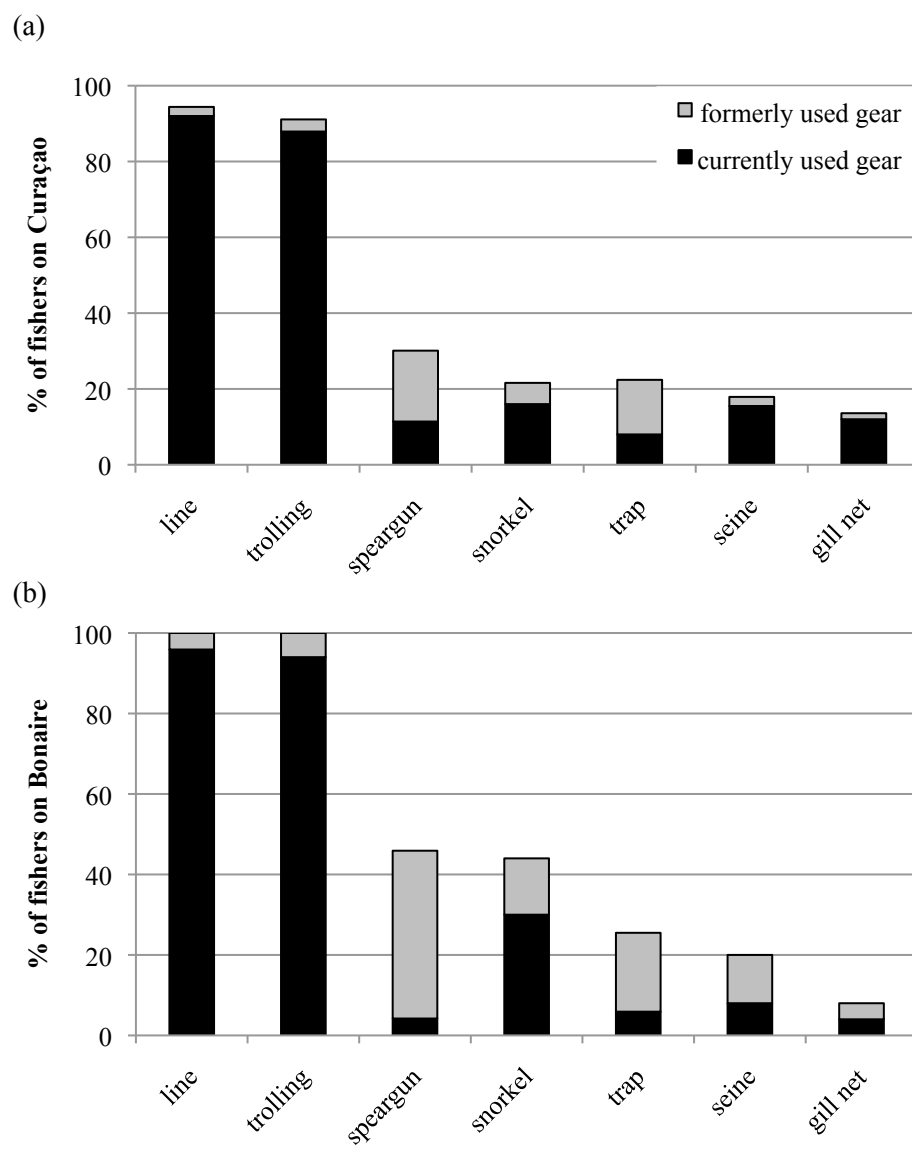
Foremost I would like to acknowledge the hospitality and friendship of the people of Curaçao and Bonaire. The views articulated were shaped by hundreds of conversations with fishers, divers, scientists, and government officials, as well as reading hundreds of articles, although this amalgamation is my own contrivance. Funding was generously provided by an NSF Graduate Research Fellowship, Switzer Foundation Environmental Fellowship, AAUW Fellowship, and the Scripps Institution of Oceanography.

Chapter 7, in full, is currently being prepared for submission for publication of the material. Johnson, Ayana Elizabeth. The dissertation author was the sole investigator and author of this material.

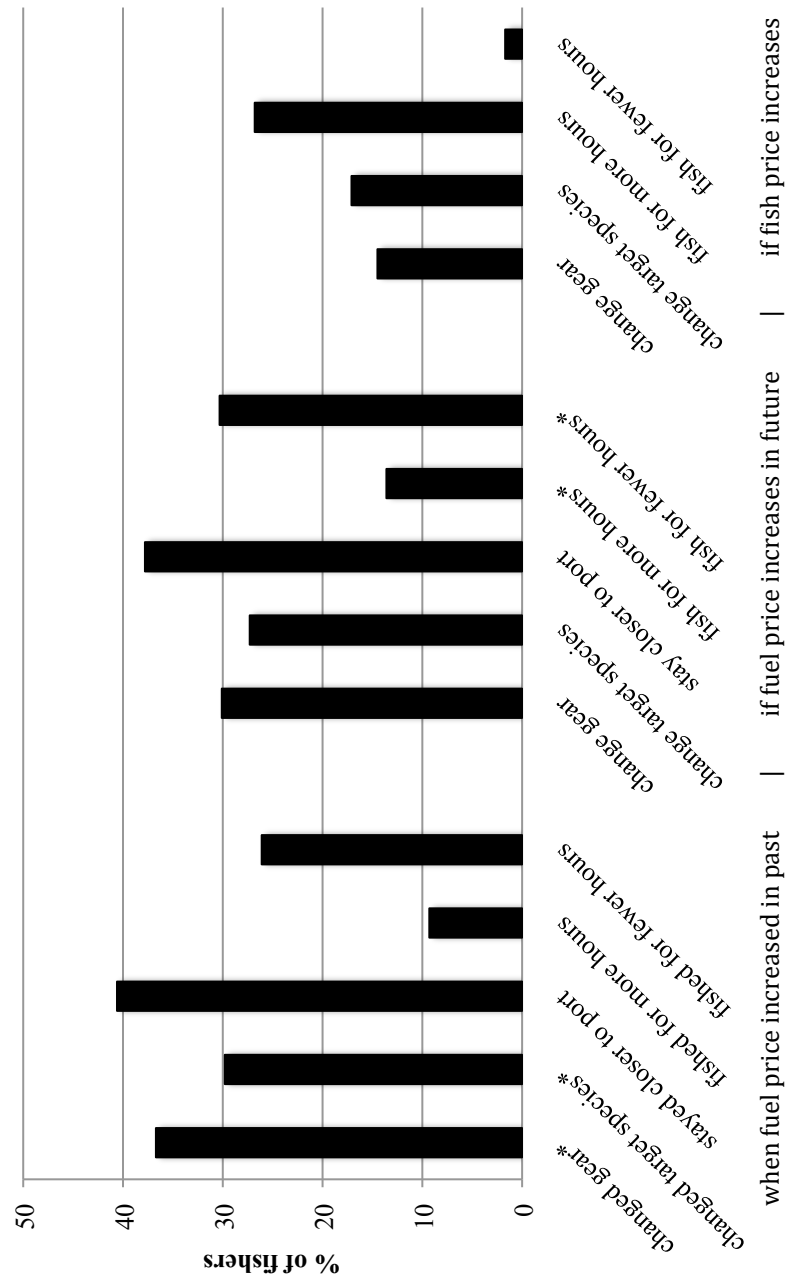
Graph 7.1. Opinions of fishers and divers on Curaçao on Bonaire about whether more or less management is needed of (a) fishing and (b) diving.



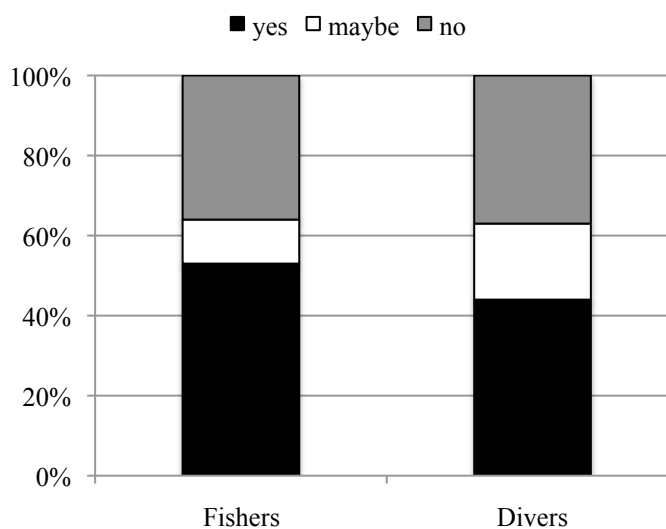
Graph 7.2. Currently and formerly used types of fishing gear on (a) Curaçao and (b) Bonaire.



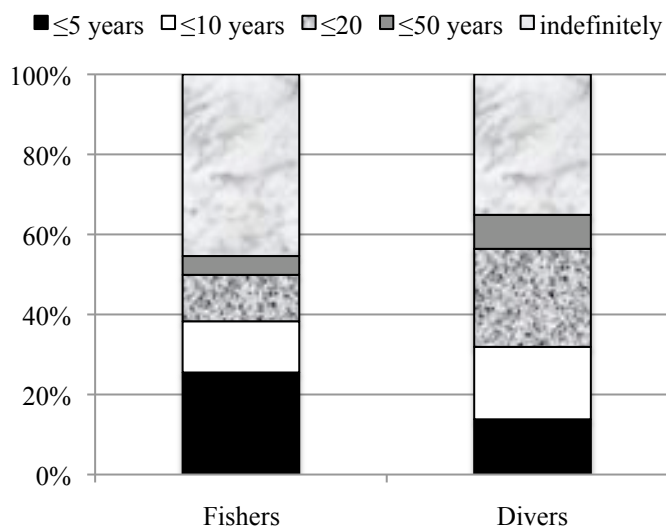
Graph 7.3. How fishers on Curaçao and Bonaire changed their fishing practices in the past when the price of fuel increased, and how their practices would change in the future if fuel price increased further or if the market value of fish increased. Asterisks indicate a significant difference in response distributions between islands ($p < 0.05$).



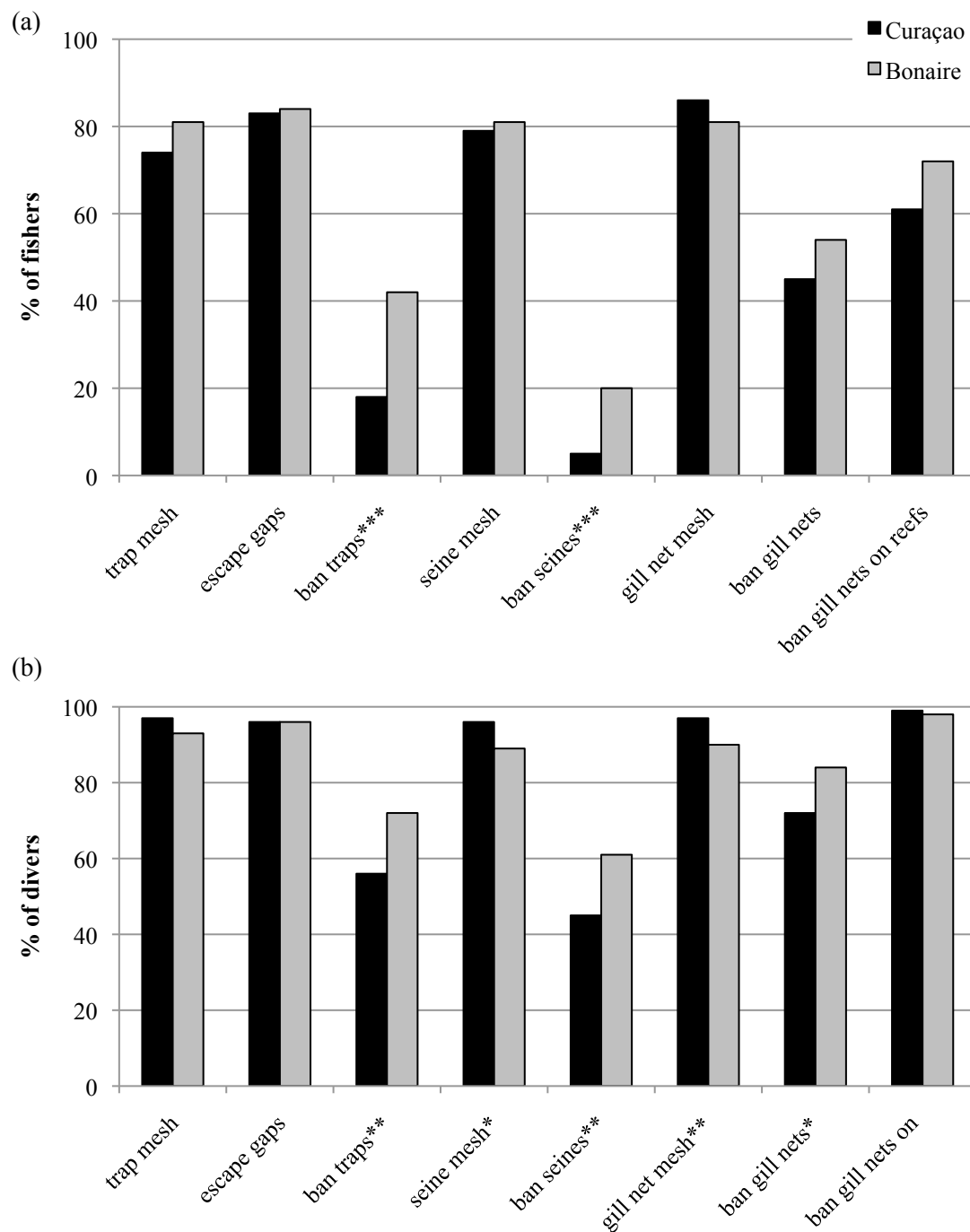
Graph 7.4. Responses of fishers and divers on Curaçao and Bonaire to the question of whether their profession is profitable. No significant differences between islands within a profession. Fishers were more likely than divers to consider their profession profitable ($p = 0.075$).



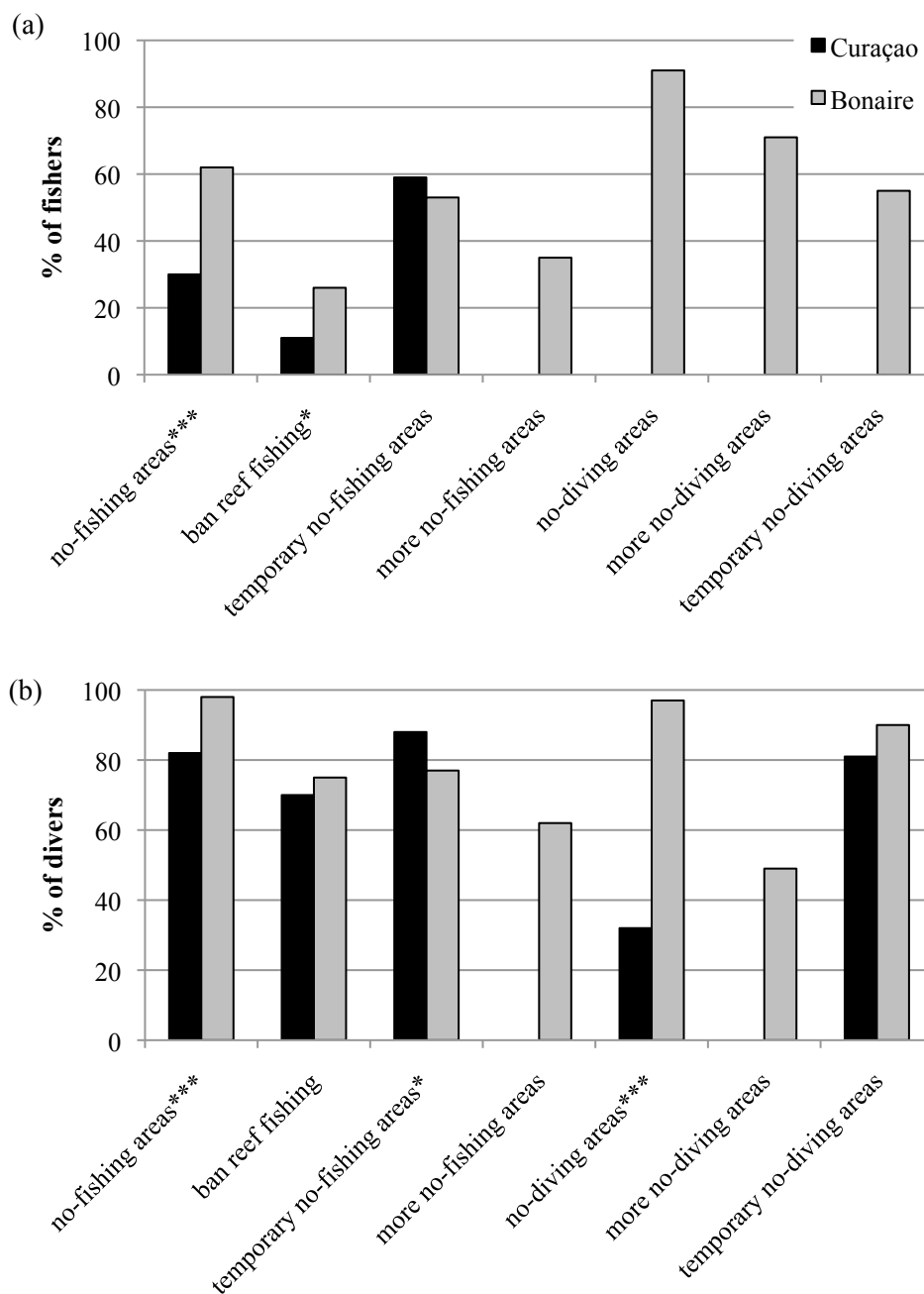
Graph 7.5. Responses of fishers and divers on Curaçao and Bonaire who believe their respective profession is currently profitable to the question of how long into the future it will continue to be profitable. Distribution of responses significantly different between professions ($p = 0.037$). Inter-island differences significant for fishers ($p = 0.046$) but not for divers.



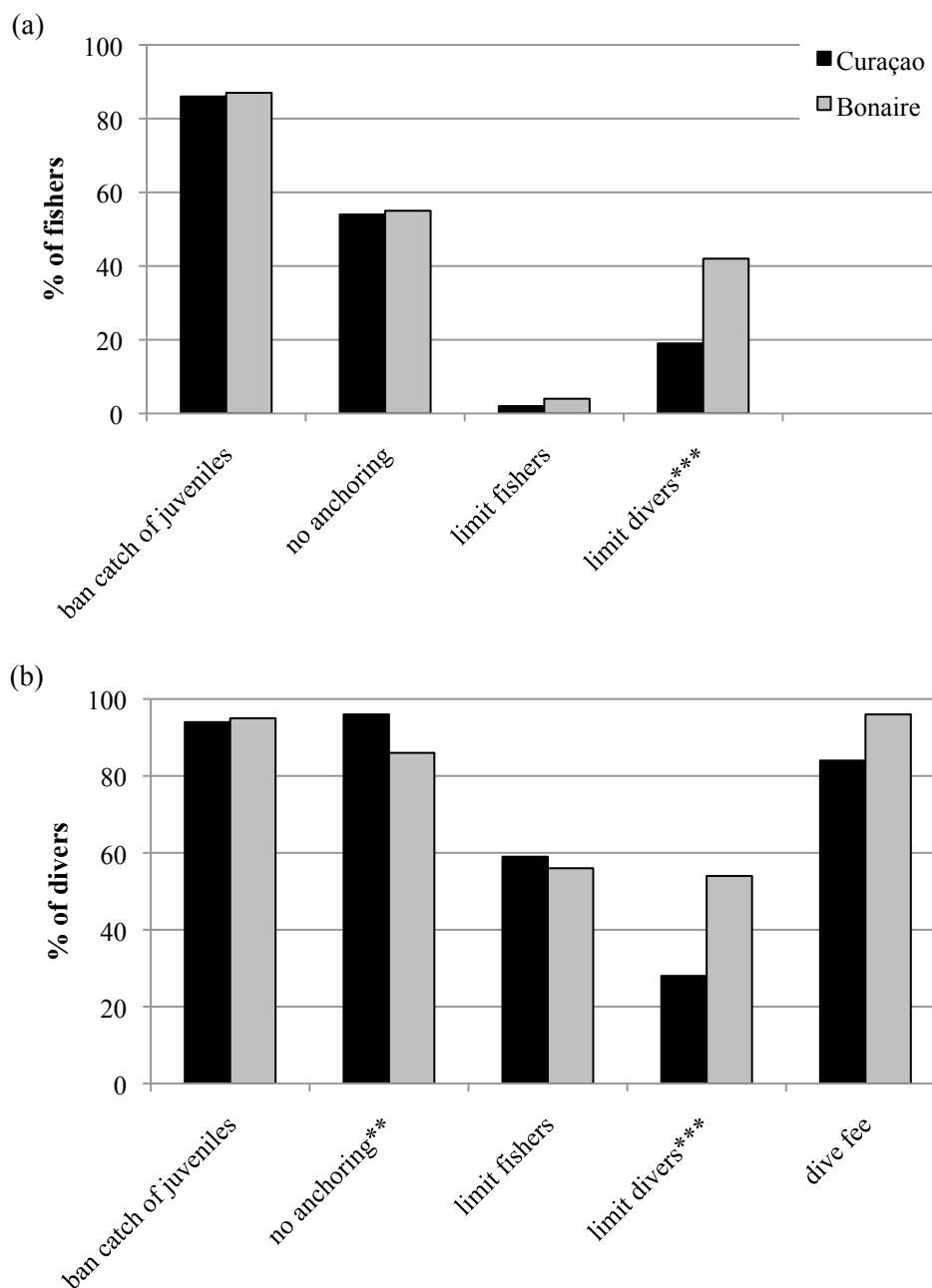
Graph 7.6. Percentages of (a) fishers and (b) divers on Curaçao and Bonaire who support various fishing gear restrictions. Asterisks indicate significant inter-island, intra-profession differences: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.005$.



Graph 7.7. Percentages of (a) fishers and (b) divers on Curaçao and Bonaire who support various area restrictions. Interviewees on Curaçao were not asked questions about whether they support *more* no fishing and no diving areas because no such areas currently exist on Curaçao. Fishers on Curaçao were not asked about their support for no diving areas. Asterisks indicate significant inter-island, intra-profession differences: * $p < 0.10$, *** $p < 0.005$.



Graph 7.8. Percentages of (a) fishers and (b) divers on Curaçao and Bonaire who support various resource management measures. Fishers were not asked whether they supported the dive fee. Asterisks indicate significant inter-island differences: ** $p < 0.05$, *** $p < 0.005$.



References

- Akapalu, W. (2008) Fishing regulations, individual discount rate, and fisherman behaviour in a developing country fishery. *Environment and Development Economics* **13**, 591-606.
- Alliance, C.R. (1991) Bonaire Marine Environment Ordinance A.B 1991 Nr.8.
- Allison, G.W., Lubchenco, J., Carr, M.H. (1998) Marine reserves are necessary but not sufficient for marine conservation. *Ecological Applications* **8**, S79-S92.
- Bak, R., Nieuwland, G., Meesters, E. (2005) Coral reef crisis in deep and shallow reefs: 30 years of constancy and change in reefs of Curacao and Bonaire. *Coral Reefs* **24**, 475-479.
- Birkeland, C., Dayton, P.K. (2005) The importance in fishery management of leaving the big ones. *Trends in Ecology & Evolution* **20**, 356-358.
- Bruckner, A.W., Bruckner, R.J. (2003) Condition of coral reefs off less developed coastlines of Curacao (Part 2: Reef fishes). *Atoll Research Bulletin*.
- Cinner, J., Aswani, S. (2007) Integrating customary management into marine conservation. *Biological Conservation* **140**, 201-216.
- Dilosun, F. (2002) Progress report Curaçao fishery monitoring program (November 2000 - July 2001). *FAO Fisheries R683 Suppl, p9-20. Available at: <http://www.fao.org/docrep/005/y4260e/74260e05.htm>*, 13.
- Gell, F., Roberts, C.M. (2003) Benefits beyond boundaries: the fishery effects of marine reserves. *Trends in Ecology & Evolution* **18**, 448-455.
- Groves, T., Squires, D. (2007) Lessons from fisheries buybacks In: *Fisheries Buybacks*. (Eds. R. Curtis, D. Squires), Blackwell Publishing, Ames, Iowa.
- Johnson, A.E. (2010) Reducing bycatch in coral reef trap fisheries: escape gaps as a step towards sustainability. *Marine Ecology Progress Series* **415**, 201-209.
- Lubchenco, J., Palumbi, S.R., Gaines, S.D., Andelman, S. (2003) Plugging a hole in the ocean: The emerging science of marine reserves. *Ecological Applications* **13**, S3-S7.
- McClanahan, T.R., Graham, N.A.J. (2005) Recovery trajectories of coral reef fish assemblages within Kenyan marine protected areas. *Marine Ecology-Progress Series* **294**, 241-248.
- McClanahan, T.R., Mangi, S.C. (2004) Gear-based management of a tropical artisanal fishery based on species selectivity and capture size. *Fisheries Management and Ecology* **11**, 51-60.
- McCook, L.J., Ayling, T., Cappo, M., *et al.* (2010) Adaptive management of the Great Barrier Reef: A globally significant demonstration of the benefits of networks of marine reserves. *Proceedings of the National Academy of Sciences* **107**, 18278-18285.

- Roberts, C.M., Bohnsack, J.A., Gell, F., Hawkins, J.P., Goodridge, R. (2001) Effects of marine reserves on adjacent fisheries. *Science* **294**, 1920-1923.
- Terk, E., Knowlton, N. (2010) The role of SCUBA diver user fees as a source of sustainable funding for coral reef marine protected areas. *Biodiversity* **11**, 78-84.
- Tratalos, J.A., Austin, T.J. (2001) Impacts of recreational SCUBA diving on coral communities of the Caribbean island of Grand Cayman. *Biological Conservation* **102**, 67-75.
- Wilhelmsson, D., Öhman, M.C., Ståhl, H., Shlesinger, Y. (1998) Artificial Reefs and Dive Tourism in Eilat, Israel. *Ambio* **27**, 764-766.
- Wilson, S.K., Fisher, R., Pratchett, M.S., *et al.* (2010) Habitat degradation and fishing effects on the size structure of coral reef fish communities. *Ecological Applications* **20**, 442-451.

APPENDIX 1: Survey of Fishermen

INTRODUCTION: I am interviewing fishermen on Curaçao to learn about the opinions of fishermen, the methods of fishing, and the types of fish that you catch. This is part of my project at a university in California. I promise that your answers will be kept completely anonymous. Any information that is published or shared will be combined results of all fishermen interviewed and will not include your name. The interview will take about 40 minutes. If you answer all the questions, there is a chance to be paid up to fl 50. Would you help me with my project by letting me interview you? Please give me *your* opinion on all questions, and just do your best to estimate what the answers are.

INTRODUCTORY QUESTIONS

1. Do you currently fish full time or part-time? ☐ full ☐ part
2. For how many years have you been fishing? Years: _____
3. Starting year: _____
4. Starting Age: _____
5. Is fishing your primary source of income? ☐ Y ☐ N
6. IF NO: Was fishing ever your primary source of income? ☐ Y ☐ N
7. Was your father a fisherman? ☐ Y ☐ N
8. How many generations of your family have been fishermen? # _____
9. Do you have children? ☐ Y ☐ N
10. IF YES: Would you like them to be fishermen? ☐ Yes for job ☐ Yes for hobby ☐ N
11. Why or why not?

BOAT QUESTIONS

12. Do you own a boat? ☐ Y ☐ N
13. Did you make it yourself? ☐ Y ☐ N
14. What year was your boat built? _____
15. Are you currently using your boat for fishing? ☐ Y ☐ N
16. IF NO: Is your boat currently functioning? ☐ Y ☐ N
17. How many feet long is it? _____ ft.
18. What horsepower is the engine? _____ horses
19. How much does it cost each year to maintain your boat? (only maintenance) Fl. _____

GENERAL CATCH QUESTIONS

On a typical fishing day

20. What time do you leave? Depart: _____
21. What port do you leave from? _____
22. How long to travel to fishing location Time: _____
23. In what areas do you most often fish? (map) #: _____
24. How many other people do you fish with? #: _____
25. Are you the captain or an assistant? ☐ captain ☐ assistant ☐ both ☐ equal
26. How many kilograms of fish do you catch? _____ kg
27. How many liters of fuel do you use in one day? Liters: _____
28. What time do you return? Return: _____
29. Total Fishing Hours: _____

On a normal fishing day, how much do you spend on

30. Boat Fuel: Fl. _____ 31. Bait: Fl. _____
 32. Assistants: Fl. _____ 33. Ice (eis): Fl. _____
 34. Other Expense: Fl. _____ 35. Total: _____

Do you sell your catch ...

36. ☐ middlemen? 37. ☐ individual people? 38. ☐ hotels?
 39. ☐ restaurants? 40. ☐ the aquarium? 41. ☐ supermarket?
 42. ☐ anyone else? Who? Other: _____

43. If you catch juvenile fish are you able to sell them? ☐ Y ☐ N ☐ don't catch

To?: _____

44. Do you use juvenile fish as bait? ☐ Y ☐ N

45. What is the smallest fish you are able to sell? _____ cm

46. If you catch ornamental fish (e.g. butterflyfish) can you sell them? ☐ Y ☐ N ☐ don't catch

To?: _____

47. Do you use ornamental fish as bait? ☐ Y ☐ N

48. Do you eat some of the fish you catch? ☐ Y ☐ N

49. IF YES: In how many meals per week do you eat fish you catch? #: _____

50. What is your favorite fish to eat? _____

51. Do you trade some of the fish you catch? For what? ☐ Y ☐ N For: _____

52. Which species do you throw back if you catch them? # _____

53. Do you ever throw back fish because they are juveniles and or/ too small? ☐ Y ☐ N

54. How many of the fish you catch on a normal day do you throw back (alive or dead)? _____ %

55. What percentage of your catch that you bring back to shore do you sell? _____ %

56. What do you use for bait? Bait: _____

57. Do you catch the bait yourself or do you buy it? ☐ catch ☐ buy ☐ both

58. IF CATCH: Do you catch it on the reef or in bays? ☐ reef ☐ bay ☐ ocean ☐ other

FISHING INCOME QUESTIONS – Yes, there is a lot of variation, but please give the average.

59. On a normal *day*, how many kilograms of fish do you sell? Kg: _____

60. How much money do you make from selling those? Total Fl.: _____ 61. Avg. Fl./kg: _____

62. In a normal *week*, how many days do you fish? #: _____

63. In a normal *week*, how much do you earn from selling fish? Days/wk: _____ * Fl./day _____ = Fl.: _____

64. In a good week, how much money do you earn from selling fish? Fl. _____

65. In a bad week, how much money do you earn from selling fish? Fl. _____

66. In the best week of fishing in your entire life, how much money did you make? Fl. _____

67. How long ago was that? Date: _____

68. In the worst week of fishing in your entire life, when you fished all week, how much did you make?

69. How long ago was that? Date: _____

70. Out of 52 weeks in a year, about how many weeks do you fish? #: ____
71. Out of the ____ weeks in a year that you fish, about how many are really good fishing weeks? #: ____
72. Out of the ____ weeks in a year that you fish, about how many are really bad fishing weeks? #: ____

ELASTICITY QUESTIONS

In the past, when the price of gas increased, did you ever change your fishing method by:

73. using a different type of fishing gear? ☐ Y ☐ N Which? _____
74. target different species? ☐ Y ☐ N Which? _____
75. fishing closer to port? ☐ Y ☐ N
76. fishing for a different number of hours per week? ☐ more ☐ less ☐ same

If the price of gas goes up further in the future, would you:

77. use a different type of fishing gear? ☐ Y ☐ N Which? _____
78. target different species? ☐ Y ☐ N Which? _____
79. fish closer to port? ☐ Y ☐ N
80. fish for a different number of hours per week? ☐ more hours ☐ less hours ☐ same hours

If the price of fish increases would you:

81. use a different type of fishing gear? ☐ Y ☐ N Which? _____
82. target different species? ☐ Y ☐ N Which? _____
83. fish for a different number of hours per week? ☐ more hours ☐ less hours ☐ same hours

SHIFTING BASELINE QUESTIONS

84. Do you think you catch more fish or less fish than previous generations? ☐ More ☐ Less ☐ Same
85. Do you think you catch bigger or smaller fish than previous generations? ☐ Bigger ☐ Sm. ☐ Same
86. Did you catch more fish this year or last year? ☐ this ☐ last
87. In the last 5 years, each year are you generally catching: ☐ more fish? ☐ fewer fish? ☐ same?
88. Have you stopped fishing in some areas because the catch there is no longer good? #: _____
89. Have you stopped fishing in some areas because there are too many divers there? #: _____
90. Do you think there are fewer fish in the ocean than there were 10 years ago? ☐ Y ☐ N
91. In the last 10 years, do you think fish catch is:

- ☐ much better? ☐ better? ☐ remained the same?
- ☐ worse? ☐ much worse? ☐ no opinion?

IF WORSENE: What do you think has caused the decline in fish catch?

92. ☐ Pollution? 93. ☐ Too much fishing?
94. ☐ Climate change? 95. ☐ SCUBA Diving?
96. ☐ Change in currents? 97. ☐ Will of God?
98. ☐ small mesh nets? 99. ☐ spearfishing?
100. ☐ coastal development? 101. ☐ Other things?

102. If there were going to be laws to manage fishing on Curaçao, what should those laws be?
103. What is the best way to make sure that the catch will be good for many more generations?
104. If there were going to be laws to manage diving on Curaçao, what should those laws be?

GEAR INVENTORY

105. Traps: # _____ 106. mesh size _____
 107. Trolling Lines: # _____ 108. line gauge _____
 109. Spools: # _____ 110. line gauge _____
 111. Hooks: # _____ 112. size _____
 113. Seine Nets # _____ 114. mesh size _____
 115. Gill nets: # _____ 116. mesh size _____
 117. Skep Net: # _____ 118. Trai Net: # _____ 119. Top Natch: # _____ 120. Bibero: # _____ 121. Rosario: # _____
 122. Speargun: _____ 123. Other types of gear? _____

GEAR QUESTIONS

124. What type of fishing gear to do you most often fish with? Gear: _____
 125. Of all the types of fishing gear, which is the most profitable type of fishing gear to use? Gear: _____
 126. Do you ever use more than one type of gear in a single fishing trip? ☐ Y ☐ N Gears: _____
 127. Do you fish with **fish traps**? ☐ Y ☐ N ☐ used to
 128. How many kanasters do normally have in the water? #: traps _____
 129. For how many days do you usually soak them before you check them? # days soak: _____
 130. What types of fish do you want to catch with kanasters? Fish #: _____
 131. What types fish do you most often catch with kanasters? Fish #: _____
 132. If fish traps had to have a rectangular hole (20 cm high by 2.5 cm wide) to let
 juvenile and skinny fish escape would you still use traps? (show sample) ☐ Y ☐ N
 133. If traps had to have this hole would make as much money using them? ☐ Y ☐ N
 134. How much does it cost you to make or buy one kanaster? Fl. _____
 Largest fish you ever caught in a kanaster?
 135. Species: _____ 136. length: _____ 137. kg: _____ 138. year: _____
 139. Do you fish with **hook and line**? ☐ Y ☐ N ☐ used to
 140. Do you hook and line fish on reefs? ☐ Y ☐ N
 141. What types of fish do you aim to catch with line? Fish #: _____
 142. What types fish do you most often catch with line? Fish #: _____
 143. How much does it cost you to buy one line setup? Fl. _____
 Largest fish you ever caught with line?
 144. Species: _____ 145. length: _____ 146. kg: _____ 147. year: _____
 148. Do you fish by **trolling**? ☐ Y ☐ N ☐ used to
 149. What types of fish do you aim to catch by trolling? Fish #: _____
 150. What types fish do you most often catch by trolling? Fish #: _____
 151. Do you troll on reefs? ☐ Y ☐ N
 152. How much does it cost you to make or buy one trolling setup? Fl. _____
 Largest fish you ever caught with trolling?
 153. Species: _____ 154. length: _____ 155. kg: _____ 156. year: _____
 157. Do you fish with a **seine net**? ☐ Y ☐ N ☐ used to
 158. How many times per month do you set your seine net? # Times: _____
 159. What types of fish do you aim to catch by seine net? Fish #: _____
 160. What types fish do you most often catch by seine net? Fish #: _____
 161. How much does it cost you to make or purchase one seine net? Fl. _____
 Largest fish you ever caught with seine?
 162. Species: _____ 163. length: _____ 164. kg: _____ 165. year: _____

166. Do you fish with a **gill net**? ☐ Y ☐ N ☐ used to
 167. How many times per week do you set gill nets? # Times: _____
 168. For how long to you leave your gill net in the water before you haul it? Soak: _____
 169. What types of fish do you aim to catch by gill net? Fish #s: _____
 170. What types fish do you most often catch by gill net? Fish #s: _____
 171. Do you use gill nets on the reefs? ☐ Y ☐ N
 172. How much does it cost you to make or purchase one gill net? Fl. _____
 Largest fish you ever caught with gill net?
 173. Species: _____ 174. length: _____ 175. kg: _____ 176. year: _____
 177. Do you fish while in the water snorkeling (i.e **snorkel fishing**)? ☐ Y ☐ N ☐ used to
 178. Do you snorkel fish on reefs? ☐ reef ☐ boca ☐ both
 179. What do you aim to catch by snorkel fishing? Fish #s: _____
 180. What do you most often catch by snorkel fishing? Fish #s: _____
 181. How much does it cost you to buy one set of equipment for snorkel fishing? Fl. _____
 What is the largest fish you ever caught with line?
 182. Species: _____ 183. length: _____ 184. kg: _____ 185. year: _____
 186. Do you **spearfish**? ☐ Y ☐ N ☐ Used to
 187. What types of fish do you aim to catch by spearfishing? Fish #s: _____
 188. What types fish do you most often catch by spearfishing? Fish #s: _____
 189. How much does a spear gun cost you? Fl. _____
 What is the largest fish you ever caught with spear?
 190. Species: _____ 191. length: _____ 192. kg: _____ 193. year: _____
 194. Do you fish with other types of gear? ☐ Y ☐ N ☐ used to
 195. What types of gear? Type: _____
 196. How often do you use that gear? Frequency: _____
 197. What types of fish do you aim to catch with this gear? Fish #s: _____
 198. What types fish do you most often catch with this gear? Fish #s: _____
 199. How much does it cost you to make or purchase one setup of this gear type? Fl. _____
 What is the largest fish you ever caught with this gear?
 200. Species: _____ 201. length: _____ 202. kg: _____ 203. year: _____

NON-FISHING ACTIVITY QUESTIONS

204. Do you consider fishing to be enjoyable or is it primarily just work? ☐ enjoy ☐ work
 205. In addition to fishing do you have a: ☐ full time job ☐ part time job ☐ no other income
☐ pension ☐ social security job: _____
 206. In a normal week how much money do you earn from these other incomes? Fl. _____
 207. In a good week how much money do you earn from these other incomes? Fl. _____
 208. Do you ever SCUBA dive? ☐ Y ☐ N 209. How frequently? _____ 210. Since? Year: _____
 211. Do you have any family members or close friends who work in the SCUBA diving industry? #: _____
 IF YES: Relationship(s) _____
 212. Gear ever damaged by divers? ☐ Y ☐ N
 213. IF YES: How often? _____
 214. What type of gear is most often damaged? _____

ENTRY/EXIT QUESTIONS

215. Why did you originally start fishing? _____
216. What would make you stop fishing? _____
217. If you could no longer be a fisherman, what would you do for a job? _____
218. Is it profitable to be a full time fisherman? ☐ Y ☐ N ☐ M
219. For how many more years do you think it will be profitable to be a fisherman? # yrs: _____

MANAGEMENT QUESTIONS

Which of the following measures do you think are necessary to improve the fisheries in Curaçao?

220. limit to how small the mesh size can be on a trap? ☐ Y ☐ N ☐ M
221. require rectangular holes in the side of traps to let small fish escape? ☐ Y ☐ N ☐ M
222. limit to how small the mesh size can be on a gill net? ☐ Y ☐ N ☐ M
223. limit to how small the mesh size can be on a seine net? ☐ Y ☐ N ☐ M
224. limit to the number of fishermen allowed to fish in Curaçao? ☐ Y ☐ N ☐ M
225. limit to the number of divers allowed to dive in Curaçao? ☐ Y ☐ N ☐ M
- Are you in favor of stopping
226. trap fishing? ☐ Y ☐ N ☐ M
227. fishing with beach seines? ☐ Y ☐ N ☐ M
228. gill net fishing in coral reef areas? ☐ Y ☐ N ☐ M
229. gill net fishing everywhere around Curacao? ☐ Y ☐ N ☐ M
230. Fishing on the coral reefs? ☐ Y ☐ N ☐ M
231. Catching juveniles? ☐ Y ☐ N ☐ M
232. Uncontrolled anchoring if the government provided buoys? ☐ Y ☐ N ☐ M
233. Are there any species you think should no longer be fished?
234. If there is one type of fishing gear that should never more be used in Curaçao, what type?
235. What is your opinion of the management of fishing on Curaçao?
Should there be: ☐ more ☐ less ☐ same amount
236. What is your opinion of the management of diving on Curaçao?
Should there be: ☐ more ☐ less ☐ same amount
237. A marine reserve is a place where no fishing is allowed so fish populations can grow and habitat can be protected. Should there be a marine reserve on Curaçao?
Permanent: ☐ Y ☐ N ☐ M 238. Temporary: ☐ Y ☐ N ☐ M
239. IF YES: Where should the reserves be? area #s: _____
240. IF NO: Would you be in favor of reserves if there were also areas where diving is not allowed?
☐ Y ☐ N ☐ M
241. Do you think that your fishing reduces the number of fish that will be in the ocean next year?
☐ Y ☐ N ☐ M
242. Does your fishing damage reefs? ☐ Y ☐ N ☐ M
243. Does anchoring damage coral reefs? ☐ Y ☐ N ☐ M
244. Which type of fishing gear do you think is the most damaging to fish populations and the coral reefs?
- | | | |
|------------------------------------|--|---------------------------------------|
| ☐ traps | ☐ hook and line | ☐ beach seines |
| ☐ trolling | ☐ speargun | ☐ gill nets |
| ☐ long line | ☐ big nets offshore | ☐ other _____ |

TIME PREFERENCE SURVEY:

Survey Instructions:

This last part of the survey will only take a few minutes. For completing these last few survey questions, you will receive up to fl. 50. All you have to do is choose how you would like to be paid: sooner or later. There are 21 questions; each is a choice between a sooner payment and a later payment. After you answer all of the questions, you will draw a chip from this bag. The chips are numbered from 1 to 21 corresponding to the numbers of the questions. You will be paid according to your choice in the question whose number is on the chip. For example, if you choose the chip with number 7 on it, you will receive the amount of money you chose in response to question 7 on the date mentioned in that question. Payments will be available for pick up on Fridays between 1pm and 5pm. I will personally be there to give you your payment. Would you like to participate in this part of the interview?

Survey Instructions:

This Friday vs. 2 weeks from this Friday?

1. Would you like to receive ☐ fl. 50 this coming Friday or ☐ fl. 50 2 weeks from this coming Friday?
2. Would you like to receive ☐ fl. 48 this coming Friday or ☐ fl. 50 2 weeks from this coming Friday?
3. Would you like to receive ☐ fl. 44 this coming Friday or ☐ fl. 50 2 weeks from this coming Friday?
4. Would you like to receive ☐ fl. 40 this coming Friday or ☐ fl. 50 2 weeks from this coming Friday?
5. Would you like to receive ☐ fl. 35 this coming Friday or ☐ fl. 50 2 weeks from this coming Friday?
6. Would you like to receive ☐ fl. 30 this coming Friday or ☐ fl. 50 2 weeks from this coming Friday?
7. Would you like to receive ☐ fl. 20 this coming Friday or ☐ fl. 50 2 weeks from this coming Friday?

This Friday vs. 1 month from this Friday?

8. Would you like to receive ☐ fl. 50 this coming Friday or ☐ fl. 50 1 month from this coming Friday?
9. Would you like to receive ☐ fl. 48 this coming Friday or ☐ fl. 50 1 month from this coming Friday?
10. Would you like to receive ☐ fl. 44 this coming Friday or ☐ fl. 50 1 month from this coming Friday?
11. Would you like to receive ☐ fl. 40 this coming Friday or ☐ fl. 50 1 month from this coming Friday?
12. Would you like to receive ☐ fl. 35 this coming Friday or ☐ fl. 50 1 month from this coming Friday?
13. Would you like to receive ☐ fl. 30 this coming Friday or ☐ fl. 50 1 month from this coming Friday?
14. Would you like to receive ☐ fl. 20 this coming Friday or ☐ fl. 50 1 month from this coming Friday?

Two weeks from Friday vs. 1 month from this Friday?

15. Would you like to receive ☐ fl. 50 2 weeks from Friday or ☐ fl. 50 1 month from Friday?
16. Would you like to receive ☐ fl. 48 2 weeks from Friday or ☐ fl. 50 1 month from Friday?
17. Would you like to receive ☐ fl. 44 2 weeks from Friday or ☐ fl. 50 1 month from Friday?
18. Would you like to receive ☐ fl. 40 2 weeks from Friday or ☐ fl. 50 1 month from Friday?
19. Would you like to receive ☐ fl. 35 2 weeks from Friday or ☐ fl. 50 1 month from Friday?
20. Would you like to receive ☐ fl. 30 2 weeks from Friday or ☐ fl. 50 1 month from Friday?
21. Would you like to receive ☐ fl. 20 2 weeks from Friday or ☐ fl. 50 1 month from Friday?

FINANCIAL QUESTIONS

245. Do you have a bank account?

☐ Y ☐ N

246. Do you have a credit card?

☐ Y ☐ N

247. Do you have a friend who would loan you fl. 50?

☐ Y ☐ N

248. How much interest would they charge you?

DEMOGRAPHIC QUESTIONS

249. Age: #: _____ 250. Are you married? ☐ Y ☐ N
251. IF YES: What is your wife's occupation? _____
252. What is the highest level of education that you have completed? _____

FINAL QUESTIONS

253. What should be done to help fishermen?

254. Anything else you'd like to tell me about diving?

255. Anything else you'd like to tell me about fishing in Curaçao?

MISCELLANEOUS:

256. Start Time: _____ 257. End Time: _____ 258. Interview length: _____ minutes
259. Interview Location: _____ 260. Date: _____
261. Disclosure Rating: _____ % 262. Translator: ☐ Y ☐ N 263. Who? _____
264. Other Comments:

APPENDIX 2: Survey of Dive Industry Employees

INTRODUCTION: I am interviewing dive industry employees on Bonaire to learn about their opinions of the health of the reefs and fish populations. This is part of my project at a university in California. I promise that your answers will be kept completely anonymous. Any information that is published or shared will be combined results of all dive industry employees interviewed and will not include your name. The interview will take about 30 minutes. If you answer all the questions, there is a chance to be paid up to fl 50. Please give me *your* opinion on all questions.

INTRODUCTORY QUESTIONS

1. Do you currently work full time or part-time in the dive industry? ☐ full ☐ part
2. Where are you from? _____
3. How old were you when you first started diving? Starting Age: _____ 4. Starting Year: _____
5. How old are you now? Current Age: _____
6. For how many years have you been diving on Bonaire? Years: _____
7. For how many years have you been working in the dive industry on Bonaire? _____
8. What is your current certification level? ☐ divemaster ☐ instructor ☐ master instructor
9. Is your work in the dive industry your primary source of income? ☐ Y ☐ N
10. IF NO: Was the dive industry ever your primary source of income? ☐ Y ☐ N
11. How many generations of your family have been divers? # _____
12. Do you have children? ☐ Y ☐ N
13. IF YES: Would you like them to be divers? ☐ Yes for job ☐ Yes for hobby ☐ N
14. Why or why not? Reason: _____
15. Are any of your family or close friends fisherman? ☐ Y ☐ N
16. IF YES: How many and what relationship? # _____ relationship: _____

GENERAL DIVE QUESTIONS

17. What dive shop do you work at? _____
18. Do you own the dive shop? ☐ Y ☐ N
19. How many years have you worked there? _____
20. Have you worked at other shops on the island? _____
21. How many diveboats does the shop have? #: _____
22. What is the capacity of the dive boat(s)? #: _____
23. In what areas do you most often dive? (map) #: _____
24. Approximately how many dives do you do per week? Work #: _____ 25. Recreational #: _____
26. What are your favorite fish/creatures to see when diving? _____
27. What is your favorite dive site? _____
28. How often is the shop's dive boat filled to capacity? _____
29. How full is the boat on a normal day? ☐ full ☐ 3/4 ☐ 1/2 ☐ 1/4
30. How often does the boat not go out because there aren't enough divers? _____

DIVING INCOME QUESTIONS

31. What is your weekly income from diving before tips? _____
32. Out of 52 weeks in a year, about how many weeks do you work as a diver? #: _____
33. How much money do you make in tips in a good week? Fl.: _____ 34. # good weeks: _____
35. How much money do you make in tips in a normal week? Fl.: _____
36. How much money do you make in tips in a bad week? Fl.: _____ 37. # bad weeks: _____
38. In the last 5 years, are there more or fewer tourists coming to dive? ☐ more ☐ fewer ☐ same

SHIFTING BASELINE QUESTIONS

39. How would you rate Bonaire's coral reefs?
☐ very unhealthy ☐ unhealthy ☐ average ☐ healthy ☐ very healthy
40. In the last 5 years, do you think Bonaire's coral reefs have gotten:
☐ much healthier ☐ healthier ☐ stayed the same ☐ worse ☐ much worse
41. How would you rate Bonaire's fish population?
☐ severely depleted ☐ depleted ☐ average ☐ abundant ☐ very abundant
42. When diving in Bonaire in the last 5 years, each year do you generally see:
☐ more fish ☐ fewer fish ☐ about the same amount
43. Have you stopped diving in some areas because the reefs there are no longer healthy? #: _____
44. Are there some areas where you don't dive because there are too many fishermen there? #: _____
45. Are there any species you used to see that you no longer see or now only see very rarely? _____
46. Do you think there are fewer fish in the ocean now than there were 10 years ago? ☐ Y ☐ N
- IF YES: What do you think has caused the decline in fish populations?
- | | | |
|--|--|---|
| 47. ☐ Pollution? | 47. ☐ Too much fishing? | 48. ☐ Climate change? |
| 49. ☐ SCUBA Diving? | 50. ☐ Change in currents? | 51. ☐ Will of God? |
| 52. ☐ small mesh nets? | 53. ☐ spearfishing? | 54. ☐ coastal development? |
| 55. ☐ Other things? _____ | | |

56. If there were going to be laws to manage fishing on Bonaire, what should those laws be?

Do you ever find that fishermen are in your way or annoying? ☐ Y ☐ N

Do you think fishermen understand divers? ☐ Y ☐ N

Do you think fishermen understand the ocean? ☐ Y ☐ N

57. If there were going to be laws to manage diving on Bonaire, what should those laws be?

58. What do you think would be the best way to make sure that the diving will be good for many more generations?

FISHING QUESTIONS

59. Do you eat fish? ☐ Y ☐ N 60. # meals per week: _____ 61. Favorite fish to eat? _____
62. Do you ever eat reef fish? ☐ Y ☐ N
63. Do you ever go fishing? ☐ Y ☐ N ☐ used to
64. If YES, how often do you fish? _____
65. Do you ever sell the fish? ☐ Y ☐ N 66. Did you ever fish to earn money? ☐ Y ☐ N
67. What type of fishing gear to do you most often fish with? Gear: _____
68. Of all the types of fishing gear, which is the most profitable type to use? Gear: _____
69. Of all the types of fishing gear, which is the most damaging to fish populations? Gear: _____
70. Of all the types of fishing gear, which is the most damaging to corals? Gear: _____
71. How often do you see fish traps when diving? Traps: _____
72. Where do you most often see traps? #: _____
73. Do you ever release the fish or damage the traps? ☐ Y ☐ N
74. Do you prevent or encourage other divers from releasing fish/damaging traps? ☐ prev. ☐ encourage
75. How often do you see nets when diving? Nets: _____
76. Where do you most often see nets? #: _____
77. Do you ever release the fish or damage the nets? ☐ Y ☐ N
78. Do you prevent or encourage other divers from releasing fish/damaging nets? ☐ prev. ☐ encourage

NON-DIVING ACTIVITY QUESTIONS

79. Do you consider diving to be enjoyable or is it primarily just work? ☐ enjoy ☐ work
80. In addition to diving do you have a: ☐ full time job ☐ part time job ☐ no other income
☐ pension ☐ social security job: _____
81. In a normal week how much money do you earn from these other incomes? Fl. _____
82. In a good week how much money do you earn from these other incomes? Fl. _____

ENTRY/EXIT QUESTIONS

83. Why did you originally start diving? _____
84. What would make you stop diving? _____
85. If you could no longer be a diver, what would you do for a job? _____
86. Do you think it is profitable to be a full time diver on Bonaire? ☐ Y ☐ N ☐ M
87. For how many more years do you think it will be profitable to be a diver on Bonaire? # yrs: _____

MANAGEMENT QUESTIONS

Which of the following measures are necessary to improve the management of fishing in Bonaire?

88. limit to how small the mesh size can be on a trap? ☐ Y ☐ N ☐ M
89. require rectangular holes in the side of traps to let small fish escape? ☐ Y ☐ N ☐ M
90. limit to the number of fishermen allowed to fish in Bonaire? ☐ Y ☐ N ☐ M
91. limit the number of people allowed to dive on Bonaire? ☐ Y ☐ N ☐ M

Which of the following do you think should be stopped:

92. trap fishing? ☐ Y ☐ N ☐ M _____
93. snorkel fishing? ☐ Y ☐ N ☐ M _____
94. fishing with beach seines? ☐ Y ☐ N ☐ M _____
95. Fishing with gill nets on the reefs? ☐ Y ☐ N ☐ M _____
96. Fishing with gill nets everywhere? ☐ Y ☐ N ☐ M _____
97. Fishing on the coral reefs (in the light blue)? ☐ Y ☐ N ☐ M _____
98. Catching juveniles? ☐ Y ☐ N ☐ M _____
99. Uncontrolled anchoring if the government provided buoys? ☐ Y ☐ N ☐ M
100. Are there any species you think should no longer be fished? _____
101. If there is one type of fishing gear that should not be used in Bonaire, what type should that be?
102. What is your opinion of the management of diving on Bonaire?
Should there be: ☐ more ☐ less ☐ same amount
103. What is your opinion of the management of fishing on Bonaire?
Should there be: ☐ more ☐ less ☐ same amount
104. Do you support the Fish Protected Areas (no fishing) on Bonaire? ☐ Y ☐ N ☐ M
105. Do you think there should be more and/or larger Fish Protected Areas on Bonaire?
☐ Y ☐ N ☐ M
106. IF YES: Where should these additional Fish Protected Areas be? area #s: _____
107. Do you think there should also be areas periodically closed to fishing? ☐ Y ☐ N ☐ M
108. Do you support the Marine Reserves (no diving/watersports) on Bonaire? ☐ Y ☐ N ☐ M
109. Do you think there should be more and/or larger areas where diving is not allowed?
☐ Y ☐ N ☐ M
110. IF YES: Where should these additional no fishing reserves be? area #s: _____
111. Do you think there should also be areas periodically closed to diving? ☐ Y ☐ N ☐ M
112. Do you support the fee charged to divers and other users? ☐ Y ☐ N ☐ M
113. IF YES: Should the fee be increased or decreased? ☐ increase ☐ decrease ☐ same 112. To? _
114. Do you think that diving damages coral reefs? ☐ Y ☐ N ☐ M
115. Do you think that anchoring damages coral reefs? ☐ Y ☐ N ☐ M

FINANCIAL QUESTIONS

116. Do you have a bank account? ☐ Y ☐ N
117. Do you have a credit card? ☐ Y ☐ N
118. Do you have a friend who would loan you fl. 50? ☐ Y ☐ N
119. How much interest would they charge you? How much? _____

DEMOGRAPHIC QUESTIONS

120. Are you married? ☐ Y ☐ N
121. If yes, what is your spouse's occupation? Occupation: _____
122. What is the highest level of education that you have completed? _____

TIME PREFERENCE SURVEY:

Survey Instructions:

This last part of the survey will only take a few minutes. For completing these last few survey questions, you will receive up to fl. 50. All you have to do is choose how you would like to be paid: sooner or later. There are 21 questions; each is a choice between a sooner payment and a later payment. After you answer all of the questions, you will draw a chip from this bag. The chips are numbered from 1 to 21 corresponding to the numbers of the questions. You will be paid according to your choice in the question whose number is on the chip. For example, if you choose the chip with number 7 on it, you will receive the amount of money you chose in response to question 7 on the date mentioned in that question. Payments will be available for pick up on Fridays between 1pm and 5pm. I will personally be there to give you your payment. Would you like to participate in this part of the interview?

Survey Instructions:

This Friday vs. 2 weeks from this Friday?

1. Would you like to receive ☐ fl. 50 this coming Friday or ☐ fl. 50 2 weeks from this coming Friday?
2. Would you like to receive ☐ fl. 48 this coming Friday or ☐ fl. 50 2 weeks from this coming Friday?
3. Would you like to receive ☐ fl. 44 this coming Friday or ☐ fl. 50 2 weeks from this coming Friday?
4. Would you like to receive ☐ fl. 40 this coming Friday or ☐ fl. 50 2 weeks from this coming Friday?
5. Would you like to receive ☐ fl. 35 this coming Friday or ☐ fl. 50 2 weeks from this coming Friday?
6. Would you like to receive ☐ fl. 30 this coming Friday or ☐ fl. 50 2 weeks from this coming Friday?
7. Would you like to receive ☐ fl. 20 this coming Friday or ☐ fl. 50 2 weeks from this coming Friday?

This Friday vs. 1 month from this Friday?

8. Would you like to receive ☐ fl. 50 this coming Friday or ☐ fl. 50 1 month from this coming Friday?
9. Would you like to receive ☐ fl. 48 this coming Friday or ☐ fl. 50 1 month from this coming Friday?
10. Would you like to receive ☐ fl. 44 this coming Friday or ☐ fl. 50 1 month from this coming Friday?
11. Would you like to receive ☐ fl. 40 this coming Friday or ☐ fl. 50 1 month from this coming Friday?
12. Would you like to receive ☐ fl. 35 this coming Friday or ☐ fl. 50 1 month from this coming Friday?
13. Would you like to receive ☐ fl. 30 this coming Friday or ☐ fl. 50 1 month from this coming Friday?
14. Would you like to receive ☐ fl. 20 this coming Friday or ☐ fl. 50 1 month from this coming Friday?

Two weeks from Friday vs. 1 month from this Friday?

15. Would you like to receive ☐ fl. 50 2 weeks from Friday or ☐ fl. 50 1 month from Friday?
16. Would you like to receive ☐ fl. 48 2 weeks from Friday or ☐ fl. 50 1 month from Friday?
17. Would you like to receive ☐ fl. 44 2 weeks from Friday or ☐ fl. 50 1 month from Friday?
18. Would you like to receive ☐ fl. 40 2 weeks from Friday or ☐ fl. 50 1 month from Friday?
19. Would you like to receive ☐ fl. 35 2 weeks from Friday or ☐ fl. 50 1 month from Friday?
20. Would you like to receive ☐ fl. 30 2 weeks from Friday or ☐ fl. 50 1 month from Friday?
21. Would you like to receive ☐ fl. 20 2 weeks from Friday or ☐ fl. 50 1 month from Friday?

FINAL QUESTIONS

123. What should be done to help the dive industry? 124. What should be done to help fishermen?

125. Anything else you'd like to tell me about diving or fishing in Bonaire?

126. Start Time: _____ 127. End Time: _____ 128. Interview length: _____ 129. Location: _____

130. Date: _____ 131. Disclosure Rating: _____ % 132. Translator: ☐ Y ☐ N

133. Who? _____ 134. Other comments: