REDUCING UNCERTAINTY IN FISHERIES MANAGEMENT:

THE TIME FOR FISHERS' ECOLOGICAL KNOWLEDGE

A Dissertation

by

LIAM MORGAN CARR

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2012

Major Subject: Geography

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Approved by:

Chair of Committee,	William Heyman
Committee Members,	Chris Houser
	Tina Mangieri
	Kim Waddell
	Jay Rooker
Head of Department,	Vatche Tchakerian

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ABSTRACT

Reducing Uncertainty in Fisheries Management:
The Time for Fishers' Ecological Knowledge. (May 2012)

Liam Morgan Carr, B.S.; B.A., University of Southern California;
M.S., Yale University
Chair of Advisory Committee: Dr. William D. Heyman

This dissertation work presents a novel method for addressing system uncertainty to improve management of a small-scale fishery in St. Croix, United States Virgin Islands. Using fishers' ecological knowledge (FEK) and fishing behavior, this research uses the Q-Method to identify regulatory inefficiencies in the management framework and strengthen the rationale for including fishers into the management process, develops a coupled behavior-economics model to predict the likelihood of fishing the preferred grounds under a range of physical and regulatory conditions, establishes a baseline assessment of a spawning aggregation of mutton snapper following 16 years of protection, and uses the discrete choice method to examine public support for FEK-based proposed regulatory alternatives. Results show that fishers largely comply with existing management strategies, as seen in the Q-Method analysis and preliminary evidence of mutton snapper population rebounding. FEK successfully was incorporated into proposed management alternatives for St. Croix that were largely supported by the public. This overarching result supports the argument for fisheries co-management.

This work contributes to a much-needed area of fisheries management, that of incorporating socioeconomic motivations within an ecosystem-based framework. Ecological goals of fishery sustainability and continued habitat function cannot be achieved without first understanding how fishers view and respond to any regulatory environment and then developing a framework that achieves the greatest support for those regulations. The time has come for incorporating FEK into ecosystem-based fisheries management.

DEDICATION

For Mom and Dad.

And the good people of St. Croix.
Especially the fishers.

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This dissertation work would not have been possible without the assistance and support of several individuals. I would like to foremost thank my advisor, Dr. Heyman, for his endless enthusiasm and commitment to ensuring that my dissertation work was both personally fulfilling and of value for improving fisheries management in St. Croix. Dr. Heyman has worked tirelessly to shape and strengthen both my academic and professional skills and it is because of his role of mentor and friend that I have been able to complete this work. I would also like to thank my entire committee, Drs. Houser, Mangini, Rooker, and Waddell, for their support during my field work, careful edits, and critical comments that improved the quality of this work. Major funding was provided by a generous grant from VI-EPSCoR. I hope that my efforts will aid the ongoing work to ensure that St. Croix continues to have a vibrant, healthy fishery well into the future.

I would like to thank Dr. Christian Brannstrom for Q-Method assistance, Dr. E. Brendan Roark for otolith work support, Dr. Ray Guillemette for providing laboratory space, and Drs. Barbara Kojis and Todd Gedamke for their field collaborations.

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NOMENCLATURE

BIRNM	Buck Island Reef National Monument
CFMC	Caribbean Fisheries Management Council
DPNR	US Virgin Islands Department of Planning and Natural Resources
EBFM	Ecosystem-Based Fisheries Management
EFH	Essential Fish Habitat
FEK	Fishers' Ecological Knowledge
MPA	Marine Protected Area
MSSAA	Mutton Snapper Spawning Aggregation Area
NMFS	NOAA National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
PFA	Principal Factor Analysis
Q	Q-Method Analysis
RHSAA	Red Hind Spawning Aggregation Area
USVI	United States Virgin Islands

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CHAPTER I
INTRODUCTION: REDUCING FISHERY UNCERTAINTY WITH FISHERS' ECOLOGICAL KNOWLEDGE: AN APPROACH TO IMPROVE ECOSYSTEM-BASED FISHERIES MANAGEMENT

1.1 Introduction

Fishery management has long been hindered by uncertainty (Ross 1896). Uncertainty can be seen in attempts to manage a large multi-species fishery with limited understanding of biological, socioeconomic factors that compel management to rely upon poorly fitting estimates of effort, production models, or healthy ecological parameters (Gordon 1954; Wilson 1982). It can also be found hampering honest efforts to assess fish stocks (Hilborn, Pikitch, and Francis 1993), or protect ecosystem-level functions and essential fish habitat (Lauck et al. 1998; Crowder et al. 2000). More recently, efforts to address uncertainty have begun to move away from single-species, single-gear approaches to a more holistic, ecologically based, ecosystem-based fisheries management (EBFM) framework (Pikitch et al. 2004; Crowder and Norse 2008; Halpern, Lester, and McCleod 2010). EBFM is heralded to be a precautionary approach (Essington 2001; Cadrin and Pastoors 2008), more conservative than single-stock management, as its aims are to protect ecosystem functionality and resilience in the face of natural and human impacts. Within the EBFM framework, the no-take marine protected area (MPA) is a commonly proposed regulatory tool. Within a fisheries context, MPAs act by severely restricting or prohibiting fishing within their boundaries. A well-situated MPA protects not just targeted stocks, but also the essential habitats and associated community that is instrumental in the overall productivity (Russ and Alcala 1999). Yet, even MPAs do not pull fisheries management fully away from the specter of management failure from unanticipated effects or sources of uncertainty in how the protected system functions and responds (Hilborn et al. 2004; Russ and Alcala 2004).

This dissertation follows the style of *Annals of the Association of American Geographers*.

To counter this insidious uncertainty, scientists have set a target of fully protecting 20-30% of the world's fishable grounds through no-take MPAs as the habitat losses (Bohnsack et al. 2000; Balmford et al. 2004). While working toward this goal is indeed important to begin addressing necessary changes in how we view and use fishery resources, in many parts of the world, they are not politically feasible (Roberts, Halpern, et al. 2001; Agardy 2003). Instead, developing and maintaining truly sustainable fisheries, through an EBFM framework or any other approach, is more likely going to be done incrementally not just because of ecological uncertainty in how to maintain the functionality of fish stock migrations and movements, protecting spawning aggregations, or deciphering how eggs and larvae disperse through a region and insuring settlement zones are healthy and safe for the next generation of fishes. Instead, as fisheries management is about "managing people" rather than fish (Berkes et al. 2001b, 12), it will also be slowed and hindered by socioeconomic uncertainty. Together, ecological and socioeconomic uncertainty represents the total "system uncertainty". And while scientists possess the skills to continue their efforts to reduce ecological uncertainty through research pursuits, their ability to address socioeconomic uncertainty remains unsophisticated, limiting any effort to reach the "overall objective of EBFM is to sustain healthy marine ecosystems and the fisheries they support" (Pikitch et al. 2004, 346).

To truly account for socioeconomic uncertainty, managers need to recognize three fundamental aspects that set it apart from ecological uncertainty, and then make steps to address them. These four aspects are: 1) the socioeconomic scale of the fishery; 2) fishers' ecological knowledge (FEK) and how it affects fishing behavior; and 3) the rapid shift of community perspectives and uses, especially as it affects fisheries management, policy development and implementation, and extent of community support

1.2 Fishery Management: The Relevance of Scale

At the conceptual level, EBFM frameworks deal with ecological uncertainty quite well. This is the underlying strength of the calls to protect 20-30% of fishing grounds. With a no-take MPA, it is no longer necessary to fully understand a stock's life history. Provide the stock with enough ecosystem functionality, and they maintain themselves. With time, these protections can provide fishery goods and services, through increased fish sizes and larger range of age classes (Burton et al. 2005; Nemeth 2005), "spillover" of fish out of the protected area and into the remaining fishing grounds (Kellner et al. 2007; McClanahan et al. 2007), and increased reproductive potential through protected spawning aggregations (Whaylen et al. 2003; Heyman and Kjerfve 2008).

Recognizing the political and socioeconomic implications of any regulation, EBFM must harness itself to scale of the fishery if it is to succeed. Large closures may not be necessary for sessile stocks, whereas a closure of any size may be insufficient for highly migratory species or capable fishing fleets (Sanchirico 2000). Furthermore, the scale of management must fit those it seeks to manage. Data collection must be done in a way that is consistent and a reflection of the grounds being studied, and not just a transfer of a technique from elsewhere that is poorly designed for the new locale (Davis and Wagner 2003). Regulations must address both current and likely trends in fishing gear selection, targeted stocks, and emerging markets and fishing communities that may further complicate the system. Most importantly, management, if it is to succeed, must show progress and positive results not just at the ecological scale of years to decades (Botsford, Castilla, and Peterson 1997) but at the scale of the fisher, who may operate under competing short (i.e. days to weeks) and long views (i.e. seasons to years) on where, when, how, and how much they fish (Kraak 2011).

All these additional concerns, too often pushed to the margins when discussing EBFM frameworks, are far more likely to be the cause of failed management. Yet, scientists and managers have little experience or tools with which to approach this added dimension of uncertainty. Fishers, however, do. For this reason, it is more imperative than ever to collect, utilize, and disseminate the knowledge, wisdom, and behaviors of fishers to more fully describe a fishery and improve its chances for successful management. Set in the fisher's relevant, short socioeconomic scale of weeks to months or seasons, FEK and behavior can qualitatively describe and assess a fishery far more completely than a scientist. More importantly, because of its tight focus on the present and near future, fishers successfully reduce system uncertainty to manageable levels by relying on their FEK to make changes in effort or fishing grounds on a daily basis. This daily interaction affords fishers with the opportunity to interact with their resource. In turn, this wealth of constantly updating information provides fishers with the ability to adaptively identify and respond to changes. This awareness and adaptability to changing conditions would be an asset to managers (Armitage et al. 2009).

1.3 Using Fishers' Ecological Knowledge to Improve EBFM

FEK (Johannes, Freeman, and Hamilton 2000) is built upon the acquired knowledge and experiences of a fisher fishing their local grounds. With experience, knowledge is gained. Fishers are able to identify essential fish habitats or predict the movement of stocks up a shelf or down a reef based on a simple foundation of recognizing and responding to environmental cues. In this manner, FEK can be used to improve EBFM (Johannes 1998, 2002), identifying those productive areas that could provide the greatest ecosystem goods and services to surrounding waters. FEK can be used to establish the best locations and times for setting up no-take MPAs. Finally, FEK brings management to those communities most dependent on fishery resources for food and livelihood (Berkes et al. 2001a, 2001b; St. Martin et al. 2007), both through the physical presence of managers seeking FEK and the assistance of fishers as well as through the ability of FEK to improve and define regulations in meaningful terms to the impacted fishing communities.

Indeed, a failure to consult or recognize FEK likely guarantees management failure (Johannes, Freeman, and Hamilton 2000; Paterson 2010). This is especially dire for small-scale fisheries (SSFs). SSFs, tend to already be hindered by mismanagement, low compliance and a lack of data (Ruddle and Hickey 2008; Béné 2009). While SSF mismanagement is more common in the developing world, particularly throughout the tropics, they are by no means alone (Cardinale and Svedäng 2008; O'Leary et al. 2011). Regulatory development and management success is unlikely to start without the support and help of fishers in SSFs, meaning that if there is to be any chance to reverse decades-long decreases in landings and ever-growing reports of imminent stock collapses at a global scale (Jackson et al. 2001; Worm et al. 2009), it must be done with all skills and knowledge and capacity to work towards sustainable EBFM goals despite uncertainty. This is why FEK is so valuable. FEK contributes information that can be used in the short-term that encourages long-term health.

1.4 The Need to Recognize Shifts in Fishery Perspectives

While much work has been done examining rapidly changing ecosystems in response to overfishing (Jackson et al. 2001; Worm et al. 2009), less well published are studies examining rapidly changing fisheries and fishing communities in response to changing ecosystems or regulations (Morgan and Chuenpagdee 2003; Ochiewo 2004). It is generally assumed that fishing effort will work toward some level of efficiency. Once efficiency begins to fall, fishers respond by targeting new stocks, new grounds, or improving the efficiency of the gear to prevent a decline in their catch and catch revenues (Tingley, Pascoe, and Coglan 2005). Yet, this response is forward-focused, while regulations remain unnecessarily rear-facing, responding to well-studied issues but unable to anticipate or respond to the next issue.

As an example relevant to this research, a gill net ban was enacted in Florida in 1994 (Anderson 2002), affecting fishers and the manufacturers of that gear. Quietly and quickly, manufacturers developed a small gill net market in St. Croix (Tobias 2004), responding to a down economy and fractured commercial fishery still recovering from Hurricane Hugo's direct hit in 1989 (Rogers and Beets 2001; Toller and Tobias 2007). Quickly, net fishing became the most efficient gear in St. Croix, accounting for over 50% of the annual catch by gear, despite only 35 fishers in St. Croix, of 215 total commercial fishers, employing it (Kojis 2004). Gill net-fishing represented a major shift in effort and harvest capacity in St. Croix at a time when managers were still working to address fish trap design (Toller and Tobias 2007).

Fishers recognized early on the harmful potential of gill netting, with nearly 40% of interviewed fishers citing gill nets as a major reason why fishing was worse in 2003 than it was in 1993 (Kojis 2004). Bottom-set gill nets were banned by executive order of the territory's governor, Charles Turnbull, in 2006 (12 VIC 9A §321-1), just as fishers were beginning to again return to fish traps (Agar et al. 2005; CFMC 2005).

The lesson of gill nets, and their subsequent ban, in St. Croix, is emblematic of how socioeconomic uncertainty can undermine EBFM goals. Research, monitoring, and regulatory development is a process that can take years (CFMC 2004, 2010), over which time, the character of a fishery, and its community may well have shifted. There is major discordance in comparing fishing and setting a course towards EBFM goals. As a second and final example, while the benefits of EBM may take years to decades to be seen (Botsford, Castilla, and Peterson 1997), and potentially after only several years of negotiations, the world will add another billion people by 2025 (Scherbov, Lutz, and Sanderson 2011). A new approach to fisheries management is needed. One that is rapid, responsive, and focused on limiting negative impacts and uncertainty today so that future issues are not compounded by the failings of the past.

1.5 Site Description

Fieldwork was completed in St. Croix, U.S. Virgin Islands (17º45'N 61º45'W), a United States island territory situated in the eastern Caribbean (Figure 1-1), from January through December 2010. St. Croix, the largest of the three major U.S. Virgin Islands at 215 km^2, lies 60 km south of its sister islands St. Thomas and St. John. St. Croix is an isolated island, separated from the Virgin Islands archipelago by the Virgin Islands Trench (4685 m depth, 60 km width). A small but important commercial fishery operates in the nearshore and shelf waters of St. Croix, employing approximately 130 full-time commercial fishers (Kojis 2004). The fishery is characteristically small-scale (Berkes 2003), with most fishing operations employing multiple gears and fishing opportunistically for several different stocks in a single trip. Unique to the U.S. Caribbean, scuba-assisted fishing is the preferred method, using spearguns to harvest fish, and hand collecting conch and spiny lobster (Kojis 2004), although fish traps and line fishing are also employed to great effect.

Fishing grounds in St. Croix include both territorial and federal waters. The Virgin Islands Department of Planning and Natural Resources (DPNR) manages territorial waters, while federal waters fall under the purview of the Department of Commerce through the Caribbean Fisheries Management Council (CFMC). Management takes the form of permanent and seasonal area closures, gear restrictions, quotas, and a commercial licensing system. Of particular interest to this research, two complementary regulations for the management of *Lutjanus analis* (Cuvier 1828), exist: a no-fishing / no-possession regulation for *L. analis* extending through all federal and territorial waters from 1 April – 30 June, and a seasonal area closure at the Mutton Snapper Spawning Aggregation Area (MSSAA) from 1 March – 30 June that prohibits all fishing activity.

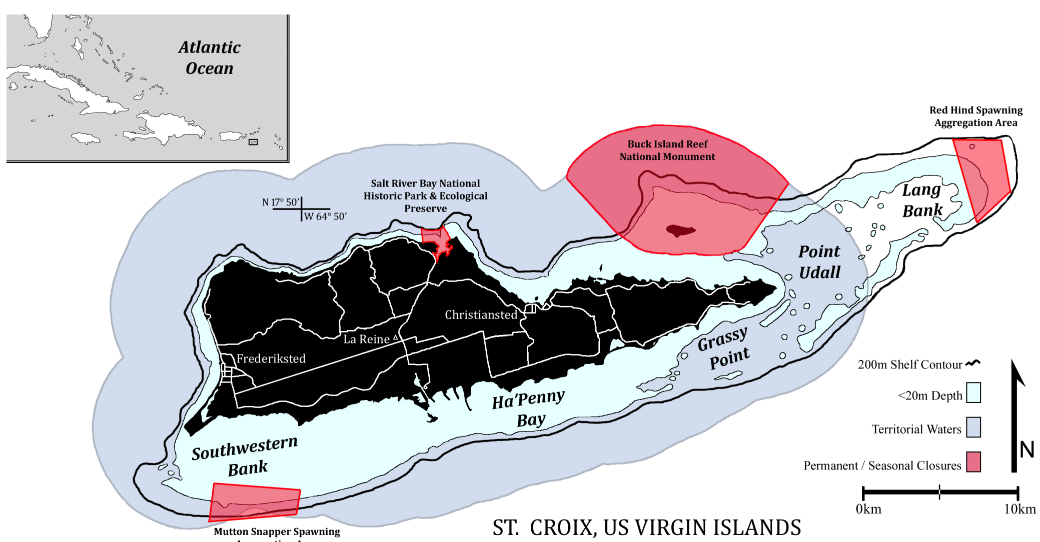

Figure 1-1. St. Croix, US Virgin Islands, with fisheries management areas.

1.6 Research Objectives

The purpose of this dissertation is to develop a methodology for reducing system uncertainty, particularly socioeconomic uncertainty, by seeking out FEK, perspectives, and response behaviors to a range of physical, market, and regulatory conditions. This FEK-based approach then builds a range of regulatory alternatives based on the words and behaviors of fishers and tests these alternatives for public support. The basic precept is that FEK-based regulatory alternatives better reflect both the ecological and socioeconomic demands of managing a fishery successfully within an EBFM framework and so would better manage system uncertainty. As a result, the strongest of these FEK-based alternatives should be considered when discussing proposals for fisheries management going forward.

This dissertation presents strategies for reducing system uncertainty, with FEK and fisher behavior as the primary tool. Recognizing that behavior is a reflection of FEK, views and biases, and socioeconomic as well as ecological demands, EBFM-based recommendations can then be made to improve fishery management in the near-term while simultaneously remaining focused and concerned about long-term health and functionality of the fishery.

CHAPTER II
"IT'S ABOUT SEEING WHAT'S ACTUALLY OUT THERE": QUANTIFYING FISHERS' ECOLOGICAL KNOWLEDGE AND BIASES IN A SMALL-SCALE COMMERCIAL FISHERY AS A PATH TOWARDS CO-MANAGEMENT

2.1 Introduction

The Magnuson-Stevens Fishery Conservation and Management Act (Magnuson-Stevens), in updating United States federal fishery regulations, directs regional fishery management councils to prepare, monitor, and revise management plans so that, "the States, the fishing industry, consumer and environmental organizations, and other interested persons to participate, and advise on, the establishment and administration of such plans" (NOAA 2007b, 3). This directive represents the clearest effort to date that federal management plans are moving to implement cooperative and deliberative relationships with stakeholders. A central goal of Magnuson-Stevens is to create inclusive, holistic, ecosystem-based fishery management (EBFM) plans that address longstanding issues of overfishing (NOAA 2010) while remaining sensitive to how stakeholders are affected by regulatory mechanisms. Yet, long-standing concerns about fishers' perceived biases and motivations remain. How these biases may undercut attempts to improve fisheries management represent a crucial hurdle to implementing cooperative EBFM programs. Hardin's (1968) 'tragedy of the commons', continues to be a familiar, if simplistic (Ostrom 2009), starting point for examining common-pool resources (CPRs), and how the economic motivations of fishers determine their exploitation patterns (Feeny et al. 1990; Ostrom 1994; Ostrom, Gardner, and Walker 1994; Feeny, Hanna, and McEvoy 1996; Dietz, Ostrom, and Stern 2003), both at the scale of small, localized fisheries (Hannesson, Salvanes, and Squires 2010) and large, transnational and fisheries (McWhinnie 2009).

Despite a ready reliance on a Hardinist paradigm and Gordon's (1954) influential work examining fishers' rational decision-making in terms of short-term economic profits, recent fisheries scholarship has begun to deconstruct this dominant precept and examine other factors that determine effort and risk of overfishing. The growing reality is that fishers also respond to non-economic interests that can reduce or reorient fishing pressure, including relationships with other fishers, fishing community pressures, or cultural norms (Jentoft, McCay, and Wilson 1998; Johannes 2002; Ostrom 2009).

Such relationships and interactions reflect the fishing community's "social capital" (Putnam 2000; Grafton 2005; Gutiérrez, Hilborn, and Defeo 2011), and over time, strengthen mutual economic benefits and community bonds (Ostrom 1994), while providing disincentives to fish in the purely profit-driven, unsustainable manner predicted by Gordon or Hardin. For tightly-knit fishing communities, this translates into pressures that can dissuade fishers from fishing in socially unacceptable, ecologically unsustainable ways. At the institutional level, social capital can motivate fishers to become involved in regulatory development and review through avenues such as public hearings or political organization, leading to the development of goals shared by fisheries managers and fishers.

This desire to participate in regulatory development and review is seen, from the perspective of this research, as an opportunity to interrogate how the social capital of a strong fishing community can improve fisheries by engaging with managers on issues relevant to their fishery. Fishers possess a unique perspective and accumulation of knowledge of their fishery, borne and strengthened over their years fishing. Johannes et al. (2000) term this as fishers' ecological knowledge (FEK) and encourage researchers to recognize its value in fisheries research and resource management. Recent FEK studies have expanded to examinations of governance and decentralizing regulatory authority back to the local level (Wilson, Raakjær, and Degnbol 2006; Begossi 2008; Silvano and Valbo-Jørgensen 2008). From here, local knowledge and influence can be brought back toward existing institutions so that co-management structures, built on the relative strengths of FEK and centralized management, can be encouraged (Koimann 2003; Berkes 2009).

FEK has been recognized as an information bridge through which resource managers and fisheries scientists can gain a fuller understanding of a fish stock, population, or grounds by seeking the experiential knowledge of fishers (Johannes, Freeman, and Hamilton 2000; Scholz et al. 2004; Hamilton et al. 2005; Begossi 2008). What FEK may lack in empiricism, it makes up for through sheer volume of knowledge along both spatial and temporal scales. Where a fisheries scientist may provide a scientifically-sound 'snapshot' of a fishing ground through a research expedition, fishers can best explain how a fishing ground has changed over the course of a few weeks, years, or decades through first-hand observations and catch reports. Fishers know how currents change well in advance of any physical oceanographer (Johannes 1981), are able to lead researchers to "previously undocumented" fish spawning aggregations (Johannes 1978), and can qualitatively describe habitat health and community structure. For these reasons and more, it is clear that involving fishers and their FEK would be useful for improving fisheries management in local contexts (St. Martin et al. 2007).

This movement away from traditional, "top-down", centralized forms of fishery management towards one that intimately involves fishers and their FEK in the management process has been termed "fisheries co-management" (Jentoft, McCay, and Wilson 1998). Magnuson-Stevens recognizes this value, stating, "policies that are developed and implemented with the full participation and consideration of all stakeholders… are more likely to be fair and equitable, and to be perceived as such" (NMFS 1999, 20). This movement toward a decentralized form of co-management imparts more responsibility on participating fishers, who may then gain a sense of ownership in the fishery and its CPRs. This transition further strengthens the fishers' social capital and desire to see a well-managed, sustainable fishery.

Nonetheless, strong, equal relationships between managers and fishers are not common (Pomeroy 1995; de Vos and van Tatenhove 2011). Distrust both between and among fishers, scientists, and managers remains an obstacle to embracing FEK or implementing co-management approaches. Not all fishers or managers are equal, and some will possess viewpoints and biases that are difficult to bridge in a co-management setting. There are fears, perhaps unfounded, that fishers who participate in fisheries management do so to reinforce their own economic futures at the sake of the resource's future health or because of distrust of partnered scientists and managers (Smith, Sainsbury, and Stevens 1999; Maurstad 2002). Such hypothetical motivations would force a direction that endangers long-term ecological sustainability and economic health for the sake of short-term profits. Instead, co-management proponents should rely upon ways of identifying fishers and managers who share common goals, recognize and respect each other, and above all, realize the critical importance of ensuring resource sustainability and functionality in ecological, economic, and social terms (Ostrom 2009).

One powerful way to identify fisher or stakeholder views and biases is to examine operant subjectivity. The Q-Method (Q) is an approach that derives its power by quantifying qualitative data like subject bias in a statistically rigorous manner (Stephenson 1953; Barry and Proops 1999; Eden, Donaldson, and Walker 2005). While Q originally was developed as a tool within the field of psychology (Stephenson 1953), it has been successfully applied into examinations on resource development, use, and governance with decidedly geographical characteristics (Robbins and Krueger 2000; Fairweather and Swaffield 2001; Eden, Donaldson, and Walker 2005; Brannstrom 2011). As such, Q is a promising approach for examining the geography of fisheries: fishing communities, the grounds they fish, and regulatory structures created to manage those fishery resources and fishers.

The use of Q and operant subjectivity analysis within fisheries management provides a geographical lens for which to reveal how fishers' FEK and biases affect regulatory development and success for managing a fishery. Knowing this relationship, fishers and managers can work cooperatively to develop locally-relevant management goals that encourage the long-term health of the fish stocks and the fishery and its community of fishers who depend upon those stocks for their livelihood and identity.

The purpose of this research is to first investigate if fishers' biases toward fishery regulatory structures in a small, commercial Caribbean fishery are distinct and identifiable compared to other stakeholder groups through the application of Q. Identifying fisher subjectivity can be used to examine how FEK and fisher bias impacts regulatory support and compliance, which can then be applied to reassess and improve management. Secondly, if fisher subjectivity is uniquely identifiable against the background of other fishers and stakeholder biases, this research then examines if these biases can be used positively to examine regulatory mechanisms of a fisher and identify opportunities to establish co-management.

2.2 Methodology

This research employs Q to quantify subject bias within a population. From January through November 2010, commercially-licensed fishers and their boat-hands were interviewed in a semi-structured setting, focusing on their perceptions on the health of St. Croix's reef fishery, existing regulations and enforcement, and the future direction of the fishery. Utilizing both opportunistic and snow-balling techniques (Biernacki and Waldorf 1981), 42 part- and full-time commercial fishers in St. Croix were interviewed. Additional interviews were conducted opportunistically with 22 individuals, representing other stakeholder groups, including dive operators, restaurant owners, fisheries scientists, environmentalists, and educators. For each interview, basic demographic information and fishing experience was recorded. Additionally, a 77-question survey focusing on St. Croix's marine resources, use, and management was administered, using a Likert scale from 1 (highly disagree) to 5 (highly agree). Likert results were tested for significance between groups using a two-sample, two-tailed t-test at the 95% confidence interval ($p \leq 0.05$).

From interviews and notes, six discourses were identified: enforcement, stock management and monitoring, temporal and area closures, licensing, and regulatory authority. Within these six discourses, 135 statements (the Q Concourse) were selected that represented the range of opinions on these subjects, from which 15 statements were selected as the final Q-Sort.

Respondents were asked to sort the 15 statements against each other in a quasi-normal curve (Table 2-1). Respondents were instructed to "rank each statement based on which would best improve fishery management for St. Croix." A total of 42 commercial fishers and 54 St. Croix residents completed the Q-Sort via both in-person and computer-based survey tools. Both sets of respondents were initially identified by approaching key figures within the commercial fishing community, local resource managers, restaurant and resort managers, dive tourism operators, educators, nongovernmental organization agents, and environmental organization staff members, and then utilizing the snowball technique to expand the sample size.

Following the Q-Sort, researchers conducted follow-up interviews to seek their sorting rationale. Each sort was scored and entered into a database, which was then analyzed using the statistical software PQMethod (v2.11). Researchers conducted principal component factor analyses and correlation analyses between sorts, identifying underlying factors through eigenvalues and z-scores. The analysis was repeated twice:

1) Q-Sort scores and correlation within all St. Croix respondents (n = 96)
2) Q-Sort scores and correlation within fisher respondents only (n = 42)

Table 2-1 Quasi-Normal Curve Distribution for 15-Statement Q-Sort

	Most Disagree		Neutral			Most Agree	
Value	-3	-2	-1	0	+1	+2	+3
Frequency	1	2	2	5	2	2	1

2.3 Results

2.3.1 Analysis of Q-Sort Scores and Correlation within All St. Croix Respondents

Q-Sort results from 96 St. Croix residents underwent principal factor analysis (PFA) using PQMethod. PFA results calculated eight eigenvalues that represented 85% of the variation within all sampled Q-Sorts. A subsequent scree test indicated that further analysis should focus on two principal factors, $F1_{stx}$ and $F2_{stx}$, which accounted for 47% of the total variation. $F1_{stx}$ and $F2_{stx}$ were then plotted against each other using varimax rotations (Figure 2-1). Q-sorts from commercial fishers were strongly associated with one another and poorly correlated to those from the general public ($r = 0.22$; $p < 0.001$). Of the 42 fishers sampled, 34 were identified as 'defining sorts' (Brown 1993) for the $F1_{stx}$ factor, subsequently defined as "Fishers". Conversely, seven of the 56 St. Croix residents tested were associated with the Fishers factor, while 27 were associated with the second factor, "Public". Of the remaining 22 residents, seven loaded more strongly towards Fishers than Public, but these results are not statistically significant. Only one fisher was strongly associated with the Public factor.

2.3.2 Analysis of Q-Sort Scores and Correlation within Fisher Respondents Only

Q-Sorts from fishers only ($n = 42$) were analyzed using PFA, following the approach described above. Again, eight factors and their eigenvalues were calculated using PQMethod. Three factors, $F1_{fisher}$, $F2_{fisher}$, and $F3_{fisher}$ accounted for 74% of the explained variation within the sample population. A scree test on the eigenvalues supported the use of three factors, which then underwent varimax rotation, and respondents were flagged as 'defining sorts' and then placed into one of the three groups represented by the factors (Table 2-2). Examination of the correlation matrix suggested further rotation of $-\pi/20$ between F1 and F3 to reduce covariance effects (Brown 1993).

Following rotation and final analysis, PQMethod calculated z-scores, which reflect the normalized weighted average within each factor group to a statement (van Exel and de Graaf 2005). Table 2-3 presents demographic information desscribing each factor group. Z-scores identified as statistically significant at ($p \leq 0.05$) and ($p \leq 0.01$) represent defining statements for each factor group (Table 2-4). This demographic information and interview statements were then used to further describe the characteristics of each identified factor group.

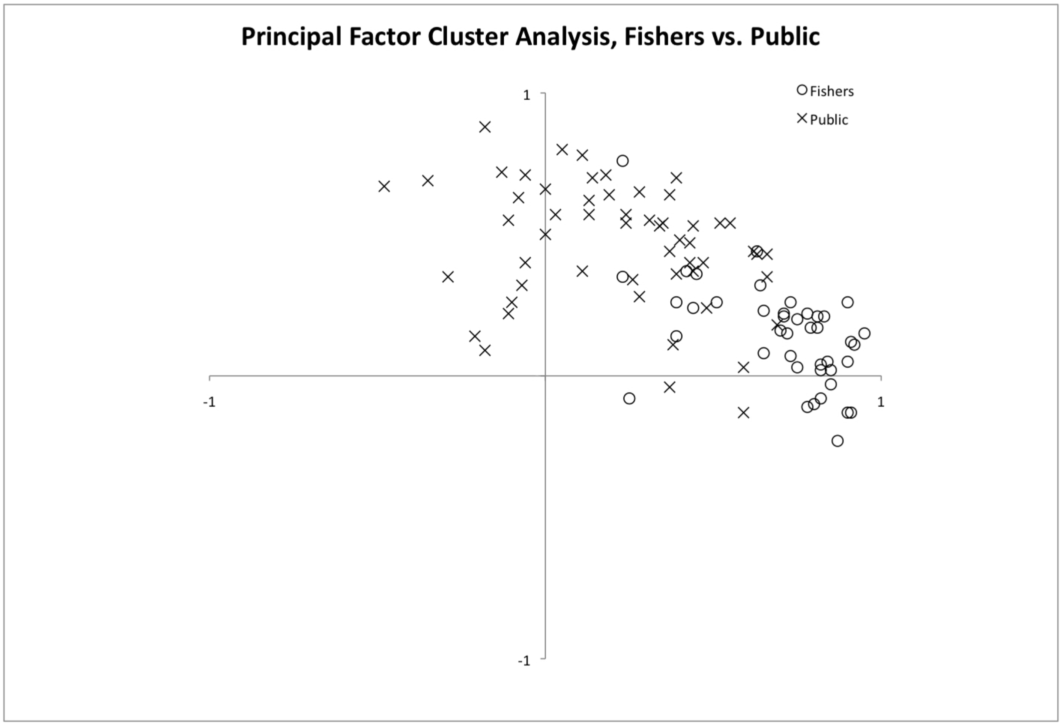

Figure 2-1. Principal factor cluster analysis of fishers versus public Q-sorts.

Table 2-2 Q-Sort Results, Fisher Respondents Only

	F1	**F2**	**F3**
No. Respondents	18	15	9
Unrotated Eigenvalues	23.16	4.79	3.12
% Variance (Rotated)	30	25	19
Correlation – F1	1.00	0.62	0.52
Correlation – F2	0.62	1.00	0.48
Correlation – F3	0.52	0.48	1.00

Table 2-3 Fisher Demographics, by Fisher Factor Group

	F1	F2	F3	ALL
No. Respondents	18	15	9	42
Age (yrs)	43.4 ± 13.5	40.4 ± 9.8	28.1 ± 14.3	39.0 ± 13.6
Commercial Experience (yrs)	23.3 ± 15.3	22.6 ± 10.6	9.4 ± 11.7	20.1 ± 13.9
No. Boat Owners	15	10	3	28
No. Full-Time Fishers	15	14	7	36
Mean No. Scuba Tanks (per fisher per day)	3.2 ± 1.7	4.3 ± 1.8	3.0 ± 1.7	3.5 ± 1.8
Mean No. Fish Traps (in use per week)	8.3 ± 14.6	5.5 ± 8.5	14.2 ± 32.9	8.6 ± 18.3

2.4 Discussion

St. Croix's commercial fisheries possess several characteristics that suggest that co-management approaches may be an improvement over existing regulatory structures. The island, an isolated seamount, has only a limited amount of shallow reef area local fishers must rely on. The fishing community itself is a cohesive and identifiable stakeholder group (Figure 2-1), with a vested interest in participating in both fisheries research and regulatory discussions. Conditions are therefore better described as CPR exploitation rather than open-access commons described by Hardin. As both interview data (Table 2-3) and Kojis (2004) show, commercial fishing in St. Croix is viewed as a full-time, long-term occupation; fishers are committed to balancing short-term economic gains with long-term income security. Based on all of these considerations, St. Croix appears as an area where co-management would work (St. Martin et al. 2007).

In terms of capitalization, fishers in St. Croix have sizeable but relatively small investments in vessels and gear compared to other fisheries. The preferred fishing vessel in St. Croix is an open-cockpit, high-walled vessel, 6.3 ± 1.6 m in length, with 90% of

Table 2-4 Factor-Loaded Z-Scores, Fisher Respondents Only
(* Significant at $p \leq 0.05$; ** Significant at $p \leq 0.01$)

STATEMENT	F1	F2	F3
Fishers who knowingly fish illegally should lose their licenses permanently.	1.63	1.61	** -1.35
St. Croix needs more fishery officers.	0.58	** -0.70	0.73
Fishery officers should be more visible within the fishing community.	-0.05	-0.06	0.03
Penalties for illegally fishing are not severe enough to deter licensed fishers.	0.85	0.98	* 1.43
Regulations against unlicensed commercial fishing should be enforced strongly.	1.28	1.04	1.42
Management should expand the use of daily catch limits.	** -1.56	** 0.93	** 0.06
Port sampling should occur monthly.	0.13	-0.18	0.12
Market prices should be raised to reduce demand without affecting fishers' incomes.	-0.58	-0.67	* -1.20
Fishers should be active in fishery research.	-0.03	0.26	0.21
Management should expand the use of permanent area closures.	-1.70	-1.78	-1.45
Management should expand the use of seasonal closures.	-1.12	-1.34	-1.62
The moratorium on new commercial fishing licenses should be lifted.	* -0.65	** -1.30	* -0.22
St. Croix needs to protect reefs and mangroves for fisheries.	** 0.17	0.62	0.73
Federal fishery regulations should match territorial fishery regulations.	1.12	** -0.03	0.81
St. Croix needs an active commercial fisher association.	-0.08	* 0.61	0.29

all registered fishing boats being less than 7.5 m in length and powered by outboard engines ranging 25 – 225 horsepower (Kojis 2004). Fishers reported paying between \$10,000 – 40,000 for their fishing boat, excluding the cost of engines, which can run towards several thousand dollars if purchased new. As scuba-assisted fishing is the preferred gear for St. Croix fishers (Kojis 2004), they must invest in dive gear, spear guns, and a supply of scuba tanks, which can surpass $1,500. In total, commercial fishers make an initial capital investment exceeding $50,000, more for fishers also interested in trap fishing ($200 – 400 in construction costs per trap).

The preference of St. Croix fishers to utilize scuba-assisted fishing gears, in addition to being manageable investments compared to other gears or fishing styles, also allows them to accrue FEK on their resource in a unique and valuable manner. Unlike other methods, spearfishing and hand collection require fishers to be underwater, directly observing the marine environment on a daily basis. Such frequent observation and *de facto* monitoring could be useful to scientists and resource managers who are trying to understand both the health of the fish community (Mackinson 2001; Sáenz-Arroyo et al. 2005), and the entire reef system in general (Miller et al. 2006). Managers have used FEK in St. Croix in the past, most notably when fishers identified a mutton snapper spawning aggregation along the island's southwestern shelf. The Mutton Snapper Spawning Aggregation Area (MSSAA) was established in 1993 to protect the aggregation from fishing in the form of a seasonal area closure (Kojis and Quinn 2011).

Despite evidence that commercial fishers are a cohesive, identifiable group against the backdrop of other stakeholders, they exhibit a range of subjectivities on fisheries management (Table 2-4). As a result, it should be expected that fishers express a range of views and responses to any proposed regulation. There may exist considerable overlap in opinions and ideas of managers and (at least some fishers) on how best to improve fisheries management. Q can help define specifically where overlaps and conflicts exist.

It is important to note that Q only identifies and groups the respondents based on correlations calculated by their individual Q-sorts. The process of defining these groups, however, is "fundamentally interpretative" (Eden, Donaldson, and Walker 2005, 419), and is performed iteratively by examining both Q statistics alongside Likert scores (S_L) and open-ended responses from interviews. The three groups are distinct enough to be identified using PFA, but perhaps owing to their shared experiences as commercial fishers in a small Caribbean island, they continue to maintain a large level of correlation with each other (Table 2-2).

2.4.1 Group F1 – The Status Quo Majority

The first group of fishers (n = 18) identified by PFA reflects the majority opinion of commercial fishers in St. Croix. This group (F1) is generally comfortable, if not fully supportive of the existing regulatory structure at both the territorial and federal levels. They consider themselves to be rule-abiding, although they share a healthy sense of pessimism that other fishers are as lawful as they are. These fishers actively avoid fishery management discussions and hearings. This group, with 23.3 ± 15.3 years of fishing experience, has a well-formed FEK, confirmed by their success and longevity as full-time commercial fishers. They are also fully invested in the fishery, with 15 of the 18 members owning at least one fishing boat. Of the three who do not, two work as equal partners on a boat with immediate family members, while the third works in the fishery only part-time.

F1 fishers generally have a skeptical view of various regulatory strategies, particularly closed seasons and areas, as evidenced by low z-scores from Q. Of the fifteen Q statements (Table 2-4), F1 fishers strongly disagreed with increasing the number of permanent area closures (z = -1.70), expanding the use of daily catch limits for demersal fish stocks (z = -1.56), and expanding the use of seasonal closures (z = -1.12). Conversely, F1 fishers had positive scores on rules that would revoke commercial licenses for illegal fishing (z = 1.63), and efforts that would lead to the harmonization of territorial and federal regulations (z = 1.12).

These Q results suggest that F1 fishers would like to see their livelihood protected by easing of their regulatory burden by ending confusion between unmatched territorial and federal regulations, which primarily concerns the collection of conch (CFMC 2009b; NOAA 2011). In interviews, these fishers base their interest in harmonizing regulations on an understanding of ecosystem functions and a belief that fluctuations in conch densities, instrumental to successful reproduction (Stoner and Ray-

Culp 2000) are affected by the losses of essential habitat due to changes in water and habitat conditions. More generally, F1 fishers are able to describe such changes in FEK terms that are important to their livelihood:

> I had spots that used to guarantee fish or lobster. Same time every day, you could go there, catch what you want in one dive. Then the reef died and the little fish leave and the big fish follow. Now I gotta find a new spot. (15 June 2010)

In addition to recognizing the value of healthy marine ecosystems and services, F1 fishers believe that illegal, unlicensed, and unreported fish landings, sold across the island in impromptu black markets are a major concern that needs to be addressed. These views are supported by F1 fisher Likert scores (Table 2-5). These fishers are not overly concerned about overfishing by licensed commercial fishers ($S_L = 3.2 \pm 1.1$). By contrast, F1 fishers are highly concerned about illegal fishing ($S_L = 4.3 \pm 0.6$), habitat quality ($S_L = 4.7 \pm 0.6$), and water pollution ($S_L = 4.4 \pm 1.0$) effects on fisheries.

2.4.2 Group F2 – The Pragmatic Conservationists

The second identified group of fishers (F2) from the Q results are unique from the other fisher groups in that they support fisher-dependent research and monitoring efforts ($z = 0.26$) and seek a unified political voice by supporting an active fisher association ($z = 0.61$). Several of these F2 fishers were active at public hearings for Magnuson-Stevens proposed rules, an indication that this group ($n = 15$) may be the most approachable in exploring co-management frameworks. Demographically, these F2 fishers are similar to F1 fishers, with a mean age of 40.4 ± 9.8 years and commercial experience of 22.6 ± 10.6 years (Table 2-4). Of the 15 respondents grouped into F2, ten are boat owners and 14 named fishing their sole occupation.

Table 2-5 Mean Likert Scores ± Standard Deviation, By Fisher Factor Group (1 - Strongly Disagree to 5 - Strongly Agree)

STATEMENT	F1	F2	F3	ALL
Marine reserves increase catch outside boundaries.	3.6 ± 1.0	3.8 ± 1.3	2.7 ± 0.7	3.4 ± 1.0
Marine reserves prevent overfishing.	2.7 ± 1.1	3.3 ± 1.2	2.1 ± 0.6	2.6 ± 1.1
Seasonal closures prevent overfishing.	3.5 ± 1.1	3.9 ± 1.3	2.2 ± 1.0	3.3 ± 1.2
Overfishing is a major issue for St. Croix fisheries.	3.2 ± 1.1	3.5 ± 1.3	2.6 ± 0.7	3.1 ± 1.1
Illegal fishing is a major issue for St. Croix's fisheries.	4.3 ± 0.6	4.4 ± 0.7	4.3 ± 0.5	4.3 ± 0.6
Water pollution is a major issue for St. Croix fisheries.	4.4 ± 1.0	4.3 ± 1.4	4.2 ± 0.5	4.3 ± 1.0
Coastal development is a major issue for St. Croix's fisheries.	3.6 ± 1.3	4.1 ± 1.1	2.8 ± 1.4	3.5 ± 1.4
Habitat quality is important for St. Croix's fisheries.	4.7 ± 0.6	4.7 ± 0.8	4.7 ± 0.5	4.7 ± 0.6
Regulations are fair to commercial fishers.	3.0 ± 1.0	3.0 ± 1.4	2.7 ± 1.0	3.0 ± 1.0
Regulations help prevent overfishing.	2.9 ± 0.9	3.1 ± 1.1	2.4 ± 0.5	2.8 ± 0.8
Your fishery needs more regulations.	1.5 ± 0.8	1.7 ± 1.0	1.6 ± 0.5	1.5 ± 0.8
Your fishery will have more regulations in 10 years.	4.1 ± 0.6	4.1 ± 0.7	4.2 ± 0.4	4.1 ± 0.6
Your fishery will be closed in 10 years.	2.4 ± 1.2	2.5 ± 1.4	2.3 ± 1.0	2.4 ± 1.1

Since F2 fishers tend to be active in public hearings, they also have been exposed to differing views, opinions and data, including those that suggest the importance of reducing fishing to sustainable levels (CFMC 2009b), recognizing that addressing commercial fishing effort is a central component for sustainable management. They possess distinct ideas on managing St. Croix's fisheries for St. Croix, an important element suggested by their significant, and weakly negative score on harmonizing federal and territorial regulations (z = -0.03).

F2 fishers seek to influence the policy-making process. This has led to several F2 fishers becoming involved in major research and monitoring efforts, and have used that time on the water to share and compare their experiences, observations and FEK with those observations and data presented from scientists. This working relationship can be built upon and further harnessed within research and monitoring partnerships in St. Croix. In fact, F2 fishers recognize that their FEK can complement scientific approaches:

> It's not about good enforcement or political power. It's about seeing what is actually out there. If you do something and go to an island and you say, "I want to see this fish or this exact reef," you will go on your own and you will not find it. But if you go and talk to a fisherman, and you say, "I want to see this specific reef" they will be able to take you. The fisherman will say, "That's no problem." And [they] will take you and drop you in right on top of one. That's what I mean. (20 May 2010)

Although there is considerable correlation between F1 and F2 fishers (r = 0.62), Q (Table 2-4) and interview (Table 2-5) results suggest that there remain real and meaningful differences between the two groups. F2 fishers tend to rely on scuba-aided fishing gears rather than a mix of fish traps and diving. This leads to additional time being spent underwater, absorbing information unavailable to those fishing from the surface, and can lead to greater reliance on their FEK:

> [Spearfishing] is really easy for me. When I go out there, I know what I'm looking for. But you get a person who doesn't know their hand from

their foot, they're not going to get anything. But, speaking for myself, I know how to fish. (21 April 2010)

2.4.3 Group F3 – The Hardinists

The third group (n = 9) identified by the PFA represents a distinctly short-term, profit-driven fisher who most readily reflects Hardin's predictions on behaviors that result in unsustainable fishery exploitation. Compared to F1 or F2 fishers, this F3 group is younger (28 ± 14 years) and less experienced (9 ± 12 years), despite having within the group the second oldest commercial fisher interviewed, 65 years with 48 years of experience. In interviews, F3 fishers had noticeably anti-conservation and anti-regulation attitudes. Many alluded to a belief that St. Croix's fisheries were open-access, and some made unambiguous statements confirming that they viewed the fishery as a resource to be fished as intensively as possible to make as much money as possible. In general, they do not believe that the fishery is in decline, but rather view fishing as a very profitable profession for those individuals who, like themselves, are self-motivated and not well suited or interested in other work sectors. Their dearth of experience also suggests an inability to recall the reefs and fish communities of twenty or thirty years ago and compare them to today, what Pauly (1995) calls the "shifting baseline syndrome". At the same time, their most formative experiences and first introductions to commercial fishing and regulatory oversight came during the early part of the past decade, when the CFMC began the lengthy but ultimately successful process of banning of gill nets in federal waters, a regulation that was subsequently adopted territorially. Interviewed F3 fishers pointed to this episode as not one that sought to eliminate a gear widely viewed as destructive and unsustainable but as regulatory over-reach, a point also seen in both public comment records and local media outlets at the time (DPNR 2005a; Lohn 2007).

Fishers on St. Croix are generally poorly educated, often entering the fishery in their mid-teens after having dropped out of school (Kojis 2004). Fishing can be highly lucrative, however, and is an appealing job for those lacking skills or interest necessary in other sectors, such as hospitality, or heavy industry. Fishing appeals to F3 fishers because it gives them the opportunity to succeed on their own and can earn them far more money than they could otherwise anticipate given their age and level of education. Yet, unlike F1 and F2 fishers, the majority of F3 fishers have not worked enough years as commercial fishers nor gathered enough experience to begin to rely on a fully formed FEK. Johannes et al. (2000, 266) describe FEK of "older fishers" as "invaluable". While not outright suggesting that researchers should discount younger fishers' FEKs, Johannes et al. do make a point that FEK is generated over a lifetime, and so should have a value that is at least partly reflective of any fisher's age or experience in the fishery. In the case of St. Croix's F3 fishers, while independently any of them may be successful fishers, their inexperience is a hindrance when it comes to approaching them for identifying problems within the fishery and its management. If all they know is personal success, regulatory battles pursued and won by fishery managers, and a foreshortened view on reef conditions, fish populations and range of sizes, they are not likely to suggest courses of action that might lead to any impact on their profits and independence as fishers. As seen in several interviews, they prize their independence and view regulations as unfair ($S_L = 2.7 \pm 1.0$) rather than as precautionary measures meant to guarantee their success as commercial fishers over their lifetime:

> I fish because I'm my own boss. (16 March 2010)

2.4.4 Perceptions of Area and Seasonal Closures as Regulatory Mechanisms

Commercial fishers have opposed expanding the size or increasing the number of permanent area closures in federally-managed waters of the U.S. Virgin Islands without first assessing the impact that existing closures have had on fisheries. This opposition was most recently focused on preventing the creation of a permanent area closure at St. Croix's productive Lang Bank (Figure 2-1) fishing grounds (CFMC 2004, 2009b). A proposal by the CFMC would have closed up to 45% of Lang Bank, but due to fisher resistance, was tabled and eventually abandoned to develop quota-based regulations. Several fishers from across the three Q-identified groups had expressed in public hearings that there was no ecological basis for the proposed closure given the CFMC's inability to assess existing closures, and that a closure of that size would both negatively affect their livelihood while forcing all fishers to move to the southwestern shelf, which would be subsequently overfished. They further argued that such a large closure would only encourage illegal fishing given ongoing issues with maintaining an adequate enforcement presence in St. Croix.

St. Croix's fishers, particularly F3-type fishers, will likely remain strongly opposed to permanent closures moving forward. The Buck Island Reef National Monument (Figure 2-1) was expanded in 2001 to include surrounding deep-water areas within the island's territorial boundaries. Yet, despite a decade of protection of what many interviewed fishers considered the healthiest reef system and best fishing in St. Croix, they state that the Buck Island closure has had a limited positive impact as a protected area, a view corroborated by Karras and Agar (2009) in an independent study.

These views are, however, potentially contradicted by fisher behaviors, suggesting that at least some fishers recognize that Buck Island serves as fisheries refugia, while providing some enhancement to surrounding fishing grounds. Four interviewed fishers admitted to engaging in illegal poaching inside the park, primarily for conch and lobster, while others, especially trap fishers, target areas along its boundaries, taking advantage of what Russ and Alcala (1996) describe as "spillover effect". Indeed, this spillover effect capacity is largely considered to be the motivation for the 2001 expansion, as the deep-water areas of the park were expected to perform as buffer areas, allowing fish a greater ability than in the original park to make daily movements along the shelf without risk of being targeted (Rogers and Beets 2001).

The reserve at Buck Island removes 15% of shelf waters from legal fishing effort (Figure 2-1). Another 6% of shelf waters have seasonal protections that prohibit fishing within red hind (1 December – 28 February) and mutton snapper (1 March – 30 June) spawning aggregation areas (DPNR 2009). Yet, scholarly suggestions of protecting at least 20% of all essential fish habitats within year-round no-take zones to combat declining fish stocks (Boersma and Parrish 1999; Roberts, Bohnsack, et al. 2001; Gell and Roberts 2003) are unlikely to be supported by fishers in the foreseeable future in St. Croix, given their resistance to the proposed Lang Bank closure and ongoing enforcement and management issues at Buck Island. This means that year-round closures at spawning aggregation sites, which have shown success both elsewhere in the U.S. Virgin Islands (Nemeth 2005) and the Florida Keys (Burton et al. 2005) are likely to continue to receive political backlash from fishers.

On the other hand, there remains a range of perspectives in the effectiveness of seasonal closures, with F2 fishers being the most open-minded, if not supportive, of closed seasons ($z = -1.12$). In contrast to F3 fishers, F2 fishers recognize that seasonal closures are effective tools to reduce overfishing ($S_L = 3.9 \pm 1.3$, $p = 0.003$), a view shared by F1 fishers ($S_L = 3.5 \pm 1.1$, $p = 0.002$). In extended interviews, F1 and F2 fishers stated that seasonal closures have increased mutton snapper sizes, though it remains a rarely sighted or caught stock by spearfishers outside of its spawning season.

Such observations reflect both a keen FEK and a recognition of compliance and potentially agreement with St. Croix-appropriate regulations, and is cautiously supported by preliminary evidence that the closed seasons for mutton snapper has a beneficial impact on its population (Kojis and Quinn 2011). Similar benefits on red hind populations from seasonal protections during its spawning season at Lang Bank have also been reported (Nemeth et al. 2007), as well as evidence of a potential recovery-in-progress of Nassau grouper and other species at a multi-species spawning site near St. Thomas (Kadison et al. 2009).

2.4.5 Perceptions on Catch Limits and Quotas as Regulatory Mechanisms

Support for daily catch limits has important consequences for fisheries management in the U.S. Virgin Islands. Currently, the only territorial quota in place, established in 2008 (CFMC 2010), limits the collection of queen conch to 200 per commercial fisher per day during the open season (DPNR 2009), which begins 1 November and runs until the annual St. Croix landings limit of 50,000 lbs. (22,680 kg) is reached.[1] In 2010, that limit was determined by DPNR to be reached or exceeded by mid-April and the fishery was closed on 30 April. In federal waters, the commercial limit is 150 per commercial fisher per day (DPNR 2009) and harmonizing regulations were enacted in 2011 to prevent continued harvesting of conch in federal waters once the territorial quota is reached (NOAA 2011). A push by fisheries managers has been made to expand quotas and catch limits to include several other important reef-associated fish stocks, particularly parrotfish, St. Croix's number one landed stock by weight (CFMC 2009a, 2010). In April 2011, the CFMC, working with fishers from St. Croix, announced a new preliminary federal quota for parrotfish landings in St. Croix (Blackburn 2011), to be set pending approval by the Department of Commerce, at 240,000 lbs. (108,862 kg).

In interviews, fishers were able to fully discuss the differences between daily catch limits and annual quotas. To them, daily catch limits have three major benefits compared to annual quotas: 1) a daily catch limit is less likely to encourage a "race to fish" than a yearly quota and is therefore a movement to an individual quota-style regulatory mechanism; 2) monitoring daily catch limits would potentially make for more adaptive management by making for real-time calculations, thereby reducing the anxiety fishers currently experience by not knowing how quickly they are working toward meeting the conch quota, and; 3) daily catch limits would better stabilize the market for a stock than an annual quota, primarily as a direct result of the first benefit listed. As a result, although there was little agreement on whether annual quotas or daily catch limits were necessary for improving fisheries in St. Croix, fishers were generally more interested in discussing the potential impacts of daily catch limits than annual quotas, leading researchers to include a daily limit statement into the Q-Sort (Table 2-4).

Annual quotas also cause unintended effects on fisher behavior in which fishers have developed strategies to ensure that a stock is available at the market, regardless of whether a season is open, without resorting to illegally fishing. On St. Croix, this is exemplified by the race to fish phenomenon of fishers taking advantage of the season

[1] This quota is a shared 100,000 lbs. (45,460 kg) quota with the St. Croix and St. Thomas – St. John districts, each receiving 50,000 lbs. at the start of conch season.

opening to catch large amounts of conch followed by long-term, deep freezer storage rather than taking the catch to the market. Fishers discussed the market incentives for them to “load up” during the open conch season, collecting more than they could sell and then freezing it. Then, they could continue to supply local conch meat, particularly to restaurants and hotels, throughout the closed season. Depending on the amount of freezer space, the value of frozen conch meat could be quite substantial. Fishers even described how they would unload their frozen conch catch at a discount, just to limit utility costs of running freezers, as St. Croix enjoys one of the highest electricity rates in the United States and its territories, $0.44 per kilowatt hour (see footnote 4).

In the case of St. Croix-caught conch, the value of having a quota and closed season appears to be the last attempt to avoid a multi-year moratorium (Freehill 2007a). St. Croix conch landings data shows that St. Croix had averaged 124,984 lbs. (56,692 kg) from 2000 – 2007 (CFMC 2010). Unpublished data[2] from 2008 – 2009 (2010 remains unavailable) show that not exceeding the quota is difficult, suggesting that monitoring and management requires considerable improvement. Fishers choosing to store conch then selling it later suggests that daily or personal quotas might be an effective regulatory mechanism, although the range of z-scores hint that a great deal of regulatory review, capacity building, and partnering with fishers will be necessary before such a regulation could be developed and implemented:

> Question: You mentioned at least once before that possession rules should extend to everybody. Not just the catching and selling of fish but also to people buying the fish. Like who?
>
> F2 fisher: Everyone. Restaurants, hotel owners.
>
> Question: Do you think [such a rule] would stop the poaching?
>
> F2 fisher: It would stop the poaching for queen conch. (20 May 2010)

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[2] Conch landings data for St. Croix district: 2006 – 230,496 lbs. (104,551kg); 2007 – 146,107 lbs. (66,273 kg); 2008 – 121,269 lbs. (55,006 kg); 2009 – 71,556 lbs. (32,457 kg). Source: NOAA National Marine Fisheries Service, Southeast Fisheries Science Center, Miami, FL

For other stocks, however, fishing effort and market demands suggest that establishing and enforcing quotas may be difficult. This is because, aside from conch, St. Croix's commercial fishers aim to catch just enough to completely sell their landings at the market:

> F2 fisher: That's all I can sell. People know me for lobster, so that's what I make the most money on. So I catch enough fish to sell. Plus that gives my helper extra money for cleaning. Keeps [the helper] happy. I don't want to throw any fish out. It just don't do me any good to freeze fish.[3] (21 April 2010)

Quotas appear to be a last resort to prevent a moratorium. In fact, one of the major reasons given for proposing the parrotfish quota was the threat of a moratorium on conch in 2007, which resulted in establishing that stock's quota. Fishers are determined not to go down that same road with parrotfish, their number one stock (NOAA 2010; Blackburn 2011). Yet, quotas may be difficult to enforce without pursuing unreported and illegal fishing, as one characteristic of the St. Croix fishery is that it is all locally consumed:

> F1 fisher: Well, I won't say there are too many [regulations]. But sometimes I think DPNR would rather make new rules than enforce the ones they got. And the new rules always make fishing harder and don't help us be better fishermen. Because it don't affect the guys fishing illegally or catching baby conch or whatever. Just us commercial fishermen who follow the rules and don't want to do anything to ruin our name or lose our license. I'm not a thief but each new rule makes me think that's what DPNR wants to call me. And then they say they know best, not we. That's not right. (15 June 2010)

[3] Deckhands and fish cleaners will clean fish for $1 per pound, and rely on this voluntary service charge as their primary source of income, as the market price goes to the fisher.

Fishers may find incentives to under-report their landings in their monthly catch reports, as some have done for conch, to meet market demand and local consumption needs while not triggering the quota:

> F3 fisher: Speaking for myself, I don't know what good the reports do for conch. DPNR must be at least month behind. So how do they know when the quota is done? And I know some guys just say "I caught this much" conch but they caught a lot more but don't want to be the guy who closed the conch season. But that's because DPNR says conch is overfished but they don't go out and see all them conch piling up in the shallows. Conch isn't overfished. (23 July 2010)

Fishers respond to market demand rather than their ability to catch as much as they can each day, adjusting their effort to peak on Thursdays and Fridays in time for Saturday's market day. If they don't sell out on a given day and can't justify the expense of an additional trip, some fishers will keep their catch on ice overnight and sell the remainder the next day.[4] Such adaptations show fishers respond efficiently to market demands by minimizing operating expenses and working inside invisible but important market-imposed "quotas" based on fluctuations in supply and demand.

The difficulty, therefore, in establishing quotas is that there remains a large gulf between what fishers would accept in terms of a set quota and what fisheries scientists estimate for sustainable yields (CFMC 2009b). This difference is accentuated by fishers' resistance to increasing prices (Table 2-4) as a market solution for reducing demand towards any lowered quota. As an example, the proposed 240,000-lbs. annual quota for parrotfish landed in St. Croix represents at least a $960,000 market, with parrotfish

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[4] Daily operating expenses are approximately $350 per fishing operation. With gasoline reaching $4.14 per gallon over the research period, itemized daily expense estimates are: $100-200 for gasoline, $100 for each boat hand and captain, $25-50 for scuba tank air fills, $25-100 for ice. Additionally, electricity on St. Croix runs $0.44 per kilowatt hour, including the Levelized Energy Adjustment Clause (LEAC), which on 14 October 2010 was $0.35 per kilowatt hour. The LEAC rate adjusts to reflect fuel purchases needed to run the island's gasoline-powered power plant, and represents the major cost for storing catch.

selling at $4 per pound. Yet, from 2006 – 2008, an average of 40 ± 4 commercial fishers landed $1.6-million of parrotfish (400,000 lbs.) annually in St. Croix, for a per fisher market share of approximately $40,000 per year (NOAA 2010). The proposed quota would reduce reported landings by 40%. Given a similar distribution of effort, the quota would average out at $24,000 per fisher per year. Fishers complain, with some validity, that lowering returns either through decreased catches or mandated quotas are what would force them to redirect effort to other less-managed stocks, thereby contravening stated goals of reducing the risk of overfishing more generally throughout the U.S. Caribbean. These stocks are currently fished at one-tenth the rate, by total landed weight, in comparison to parrotfishes (NOAA 2010). Increasing the catch of alternate stocks would require greater effort and therefore additional increases in operating expenses or switching gear selection from scuba-assisted fishing, which has essentially zero by-catch, to more efficient fish traps, which have numerous ecological impacts (van der Knaap 1993; Johnson 2010). Such a scenario would cause unintended effects at the ecosystem level, likely requiring additional regulations not currently anticipated by the parrotfish quota.

2.4.6 Perceptions on the Need for Enforcement

All interviewed fishers identified the lack of enforcement as a major problem of the fishery. This view suggests that commercial fishers have already a strong sense of ownership of the resource and want to restrict commercial fishing to only those recognized by their own community as fellow fishers. This ownership is a principal and necessary component if management is to move away from Hardinist, open-access outcomes (Botsford, Castilla, and Peterson 1997; Hilborn 2007c; Ostrom 2009). In St. Croix, licensed fishers resent the efforts of unlicensed fishers, described in several interviews to be akin to thievery. They place the blame of continued unlicensed and illegal commercial fishing at the feet of DPNR:

> F1 fisher: No. I think that they have a job and they don’t do it. We fish and we follow the rules. But there are guys who aren’t commercial fishers and they fish and sell and nobody does nothing. Or there are guys who still use nets, and they know they can’t. But [DPNR] doesn’t get out from behind their desks. (7 May 2010)

Fishers feel that management should be conducted similarly to how fishers themselves operate, with early hours and work through the weekend, with a dedicated fisheries division responsible for the science, monitoring, and enforcement of fisheries regulations:

> F1 fisher: [DPNR needs to] wake up at 5am, go to the launch and see who is there. Then go to their spots where they sell. They know who is who. Not that hard. But they just sit there and [an unlicensed fisher] arrives and drives right past. But with us, it’s “where’s your report?” I swear. (24 July 2010)

Examining the range of opinions between groups, F1 members appear to be satisfied with the amount and style of regulations in place and only wish to see a more effective enforcement presence from DPNR, particularly in reducing unlicensed fishing and poaching by licensed fishers. In Likert surveys (Table 2-5), F1 fishers scored the lowest on the statement ‘your fishery needs more regulations’ ($S_L = 1.5 \pm 0.8$) while remaining unconvinced that regulations prevent overfishing ($S_L = 2.9 \pm 0.9$), or that overfishing is even a concern for St. Croix’s fisheries ($S_L = 3.2 \pm 1.1$). Yet, F1 fishers do consider illegal fishing (i.e. unlicensed fishers catching and selling commercially, as well as licensed fishers fishing through a closed season or in a closed area), to be a major issue ($S_L = 4.3 \pm 0.6$). For F1 fishers, addressing illegal fishing should be the priority, yet their twenty years of experience working through seemingly endless regulatory reviews and updates fuels their sense of resignation that DPNR and CFMC will instead opt to develop more regulations in ten years ($S_L = 4.1 \pm 0.6$) rather than review and enforce existing regulations.

Similarly, F2 members responded most positively to regulations that would lead to permanent revocation of licenses by those fishing illegally ($z = 1.62$), and that illegal fishing was a major problem ($S_L = 4.4 \pm 0.7$). F2 fishers are uncertain on the benefits of harmonizing federal and territory regulations ($z = -0.03$), while F1 and F3 fishers broadly support such efforts ($z = 1.12$ and $z = 0.81$ respectively). In interviews, F2 fishers expressed frustrations with the unevenness of enforcement by local agents and a lack of understanding on local fishery issues by federal agents:

> F2 fisher: The way I see things, the local laws just apply to certain people. And the federal laws, nobody is around to know if someone breaks one. Since [conch] lands here, everyone just assumes it's local. (15 May 2010)

> F2 fisher: What I don't like is how the [CFMC] makes all the decisions and they don't even come here, and DPNR just accepts it and [suggests] a local law for it. All their data is for Puerto Rico, or St. Thomas for that fish trap study [(NMFS 2006)]. Do we use traps? Nothing close to St. Thomas. Are we Puerto Rico? We're like one little town in Puerto Rico. You tell me that we should all be treated the same. We fish with spearguns. The Council didn't even know if spearguns were legal gear [note: they are]. But all the money and the research goes to Puerto Rico, and then they make our decisions for us. Do we need more research? Absolutely. That's how we start to manage ourselves. (12 May 2010)

F3 fishers had the greatest range of views on enforcement in St. Croix's fisheries. They support strengthening penalties for illegal fishing ($z = 1.44$), harmonizing regulations between federal and territorial waters ($z = 0.81$), and, in sharp contrast to F2 fishers being opposed to increasing the number of enforcement agents (z = -0.70), F3 fishers believe that enforcement capacity should be increased (z = 0.73). Like F1 and F2 fishers, the F3 group would like agents to enforce regulations against those engaged in unlicensed commercial fishing (z = 1.42):

> F3 fisher: I've had places where my [catch] is out and [unlicensed fishers] come set up next to me and a customer will come and they'll say "I'll give it to you for less," when he's selling it for $5 a pound and I'm selling it for $7. Right next to you. They don't give a damn. Nothing. And you know [DPNR] know who has licenses. But they're too busy trying to take mine. Maybe they're afraid of them. Like they'll pull a gun or something? Come on. They're stealing from us and DPNR just sits there and smiles. (7 June 2010)

F3 fishers were unique in that they feel that a fisher should not lose their license permanently for being caught illegally fishing (z = -1.35). In interviews, F3 fishers who sorted this statement low (-3 or -2 values), were asked directly why they didn't believe in license revocation. They gave a range of opinions, but many centered around two themes: it was wrong to take someone's livelihood, or that the regulation itself was flawed and that illegal fishing was only illegal in a legal sense, but wasn't having an impact on the fishery or the overall health of the reef and fish communities. Both of these perspectives provide evidence of the over-riding character of F3 fishers being "Hardinists", along with a developing FEK that reaffirms their generally negative views on managers and regulations.

Within the F3 group, there is a need to demonstrate a complete understanding of their marine environment, and necessarily, one that is superior to other views, particularly those of adversarial scientists, managers, and enforcement agents. This view leads to a tendency to discount regulations and management approaches, which they knowingly break, or at least openly disagree with. Yet, they understand the political context and their position within the political sphere of fisheries in St. Croix, and so in an acknowledgement of their self-preservation, would prefer not to risk themselves losing their own licenses, leading to the view that licenses shouldn't be revoked for illegal fishing:

> F3 fisher: I fish all over. God made the sea and it is free. Nobody can rule it. I fish Buck Island. There's nobody there [to enforce poaching]. And if someone comes, we see them and take off… I catch the most fish at the market. Six days a week. If we were overfishing, could I catch that much fish? No. God makes sure there's fish for me to catch. And I make sure there's fish to eat. (20 May 2010)

While commercial fishers continue to seek a more active enforcement presence in St. Croix, one particular regulatory mechanism has worked to quietly to reduce the overall fishing effort throughout the territory while simultaneously improving compliance for other regulations: the moratorium on the issuance of new commercial fishing licenses. This moratorium has resulted in a slow but steady erosion of the commercial fishing fleet, through retirement, voluntary departure, or loss of license through either a failure to keep the license current or revocation. Interestingly, the moratorium, which affects all three major islands in the territory, was introduced and is supported only by St. Croix fishers (CFMC 2010). The moratorium, first enacted on 24 August 2001, remains an active negotiation, with fishers and managers continually discussing whether to lift the moratorium and, if so, how to go about it. While all three fisher groups identified by Q do not support lifting the moratorium, F3 fishers' z-scores are weaker ($z = -0.22$) than either F2 ($z = -1.30$) or F1 ($z = -0.65$) fishers, suggesting that the moratorium issue is a minor issue to them (it ranks tenth out of the fifteen Q statements in absolute value scores). For F2 fishers, the moratorium represents the fourth largest issue assessed, behind the use of permanent closed areas, seasonal closures, and illegal fishing, while for F1 fishers, it ranked seventh.

The original impetus of the moratorium was to prevent large-scale entry into the fishery following territory-wide economic turndowns in the late 1990s while simultaneously removing from the fisher rolls those who held onto licenses but weren't fishing (DPNR 2009). Commercial fishing licenses, which continue to cost $5 annually, were seen as economic and subsistence safety nets, regardless of fishing ability. In 2001, St. Croix was still rebuilding from Hurricane Hugo's direct hit in 1989, and long-time commercial fishers had become increasingly worried about competition from the arrival of new fishers. They successfully petitioned for the moratorium, which only allowed fishers to continue to be licensed if they were first licensed before 24 August 1998 and maintained necessary registration paperwork and catch reports each year, regardless of whether or not they were active in the fishery. Illegal fishing or failure to submit reports could (and has) led to license forfeiture, although a process of appeals exists and the number of forfeitures remains behind other means of attrition out of the fishery.

As z-scores from the Q show, support for the moratorium continues to remain strong within both F1 and F2 fishers, yet there is some practical differences in how they view both the role and function of it. F1 fishers, who do not wish to be bothered or disturbed by regulations, view the moratorium as a primary task and occupation for DPNR, and to be approached hand-in-hand with enforcing unlicensed fishing effort:

> F1 fisher: I think [the moratorium] is working. We had too many people who didn't know how to fish trying to catch something and then wondering why they weren't making money. Either you're a fisherman or you're not. The moratorium helps to make sure you're a fisherman. And it gives DPNR a way to watch everybody. You can't just say you once were a fisherman. You have to be a fisherman. You have to go out there and catch fish. You have to show what you caught. Too many people

> were holding on to a license, saying they fished or were fisherman, but they'd get lost trying to get to Green Cay.[5] (18 May 2010)

Meanwhile, F2 fishers consider the moratorium to be an important tool for removing those fishers whose catch, appearance, or demeanor make the public less inclined to visit the market. In essence, maintaining a commercial license represents a stamp ensuring quality fish:

> F2 fisher: [My license] tells people I know what I'm doing. It tells people that they can trust me. That my fish is fresh. My customers have known me for a long time. They like what I catch. (20 May 2010)

F1 and F2 fishers recognize that the moratorium gives them competitive market advantages, and that their continued ability to renew their license and sell their landings is a *de facto* endorsement from fisheries managers that they are fishing in a proper, legal, and conservation-minded manner. As a result, F1 and F2 fishers do not feel the need to jeopardize their license by illegally fishing. Experienced and able to turn a profit repeatedly over many weeks, months, and years, these fishers move away from treating the fishery as open-access and instead view the fishery from the perspective of owner.

While it is likely that the moratorium creates pressures that encourage unlicensed fishing, the general opinion of F1 and F2 fishers is that fishing conditions would be worse without it. This view, while not as strongly held by F3 fishers, has been separately described during interviews with fisheries managers:

> Manager: The moratorium will continue to be difficult to maintain if the economic conditions [in the U.S. Virgin Islands] continue to be bad. But as it was planned, it has been successful. There were fishermen who

[5] Green Cay is the first inlet one approaches after launching from Altona Lagoon, east of Christiansted. The cay lies approximately 200 meters to the north of St. Croix.

> treated the license like a right, and wouldn't fill reports or even bother telling us if they fished that month. And remember, we were also beginning to try to ban gill nets at the time, and there were about ten fishermen who heavily used [gill nets]. And they caused problems, and the newspapers called them out. So we get rid of the gill nets and some fishermen complain they can't make enough money because all they knew how to do was either gill net or buy fish off the gill netters. But they had that license. That's why they were throwing away fish they caught [(Toller and Tobias 2007)]. It was bad fish. Get rid of those nets and they didn't want to be fishermen anymore. Who did that benefit? The fishermen who had been working hard all along. (24 March 2009)

One final point concerning the direction of fisheries management and enforcement in St. Croix is the recognition that policy makers need to work to build compliance and support for regulations. F1 and F2 fishers remain concerned about the health of their fishery, their ability of bringing a quality catch to market, and the overall perception on how the public views fishers and their community. A failure by regulators to provide the necessary oversight, monitoring, and enforcement that safeguards the livelihood of rule-abiding fishers can serve to weaken future partnerships between fishers and managers, especially cooperative management initiatives. Fishers from all three groups recognize the effects that fishing has on marine resources and the effects that arise from habitat loss, development, pollution, and coral damages and disease. If managers show initiative in addressing upstream issues, they will likely see increased support of commercial fishers for those policies that are focused on managing the fishery directly, including improved data collection and accurate, timely catch reports.

2.4.7 Perceptions on the Role of Habitats for Maintaining Fishery Functionality

All three fisher groups had positive z-scores from Q on the statement "St. Croix needs to protect reefs and mangroves for fisheries" (Table 2-4), although the relatively low positive score of F1 ($z = 0.17$) was significantly distinct from F2 ($z = 0.62$) and F3 ($z = 0.73$). In interviews and Likert surveys, fishers from all groups were able to tightly connect the value of healthy reefs, mangroves, seagrasses, and other nearshore areas to productive fisheries. The mean Likert score for all 42 surveyed fishers for the statement "Habitat quality is important to your fishery" was the highest of the fourteen statements posed ($S_L = 4.7 \pm 0.6$). These results suggest that St. Croix's commercial fishers recognize the importance of ecosystem-level effects on their fishery resources, and share this recognition with EBFM proponents (e.g. Pikitch et al. 2004). In this regard, fishers may be ahead of policy-makers, who are confined by the inertia of regulatory development and review that remains a major obstacle to improving "top-down" management regimes (Scheffer, Westley, and Brock 2003; Folke et al. 2005) in demanding that ecosystem level effects on fisheries must be addressed. Pikitch et al. (2004), identified three core statements that define EBFM, each of which was echoed in interviews by fishers:

> Pikitch et al.: EBFM should avoid degradation of ecosystems, as indicated by environmental quality and system status.
> F2 fisher: We need to protect places for the fish to grow up and get big and healthy. (15 June 2010)

> Pikitch et al.: EBFM should minimize the risk of irreversible change to natural assemblages of species and ecosystem processes.
> F1 fisher: Conch love the seagrass and I know lots of snapper come into the mangroves we got. You let it die, and the fish leave. That's not the fisherman's fault. (27 May 2010)

> Pikitch et al.: EBFM should provide long-term socioeconomic benefits without compromising the ecosystem.

> F1 fisher: The first thing they need to do is see what needs to be closed. If this is a spawning area, leave it closed. I don't mind that. (24 July 2010)

There is a legitimate concern for fishers in St. Croix to be worried about the health of the marine environment. The entire southwestern reef system experiences persistent industrial-scale pollution (Rothenberger et al. 2008). In addition to the Hovensa Oil Refinery and its port (Port Molasses), there exists an abandoned and not fully mitigated aluminum plant (Alcoa Inc.), two rum factories (Cruzan Rum and Captain Morgan Rum), the island's public landfill, Henry E. Rohlsen Airport, and a wastewater outfall. Wind-driven currents tend to be westerly and carry pollutants away from this industrial complex towards productive reefs, seagrass beds, the MSSAA, and Sandy Point, an active nesting beach for the endangered leatherback sea turtle. Federal agencies have recognized that the concentration of heavy industry so close to productive marine ecosystems will require special attention, and as a result, the entire southwestern coast and associated nearshore waters of St. Croix has been listed by NOAA as an Area of Particular Concern, or APC (Rothenberger et al. 2008).

Fishers recognize that St. Croix, particularly the South Coast Industrial APC, is persistently stressed by water pollution, eutrophication, and coastal development. The southwestern grounds are also identified to be the island's second-most productive fishery behind Lang Bank. Fishers recognize that the health of the reefs and back-reef seagrass beds and mangroves are critical to the health of the fishery. They observed large-scale coral losses from the 2005 bleaching and subsequent disease outbreak (Miller et al. 2009). Fishers from all groups expressed exasperation at the loss of reef, linking the industrialized area and its pollution impacts on fish stocks, something they recognized was beyond their control:

> F1 fisher: Hess [Hovensa Oil Refinery] and Cruzan Rum have been there for what, 100 years? And they're going to be there another 100 before anyone makes them clean up.[6] (24 July 2010)

> F2 fisher: I helped [the University of the Virgin Islands] in 2004 and 2005 out west, and in one year, you saw the reef change. That's not the fisher. That's Hess. That's coral bleaching. That's rain bringing all that pollution into the water. That's not the fisher. But when there's no juveniles the next year, and we don't see the same fish on the reefs, everyone says it's the fisherman's fault. Because everybody is afraid to blame Hess or Cruzan Rum. (20 May 2010)

> F3 fisher: Every time it rains hard, you know what DPNR do? They close the beach. Too much pollution in the water. Don't want nobody to get sick. Guess where there's always too much pollution? Hess. The reef is dead. Or dying. But they [DPNR] don't do anything. (18 May 2010)

2.4.8 Utilizing FEK in a Co-Management Framework

Since FEK is a lifelong accumulation of experiential knowledge, resource managers should seek to develop and maintain positive, long-term working relationships with fishers. Younger fishers, despite clearly different economic goals, should be approached however, and encouraged either directly or indirectly over time, to engage in co-management as they represent the future of fishing effort. As trust develops, fishers are more likely to be honest and willing to work alongside managers (de Vos and van Tatenhove 2011). This trust is ultimately the foundation from which fisheries co-management approaches will succeed.

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[6] On 18 January 2012, Hovensa LLC announced that it would be ceasing refinery operations by 1 March 2012, and converting the refinery into an oil storage facility. The closure, which would directly cause the loss of at least 2000 jobs in St. Croix, was deemed necessary by the parent companies of Hess Oil and Venzuelan-owned Petroleos de Venezuela because of spiraling losses associated with the oil-powered refinery, which was the third largest, by capacity, in the United States in 2010.

From the perspective of encouraging and strengthening co-management opportunities, managers need to realize that many fishers are likely to behave similar to the F1 fishers identified in this study, in that while they may not be initially interested in working with researchers or managers ($z = -0.03$), they do carefully watch the proceedings as they go about their own business. These fishers recognize when regulations work and where policy makers respect and seek out the opinions of fishers during regulatory development or review. As they will likely represent the majority of a fishing community, their tacit support is crucial for any co-management prospects since, within the fishing community, their seniority and views hold tremendous weight.

On the other hand, inexperienced, F3-type fishers may lack the incentive or perspective to be initially interested in co-management programs. In the case of St. Croix's F3 fishers, the combination of their immediate success upon entering and relative lack of personal or family obligations compared to older fishers has allowed them to enjoy tremendous profits which further motivates their intense style of fishing. This is not to say that they should be ignored. As the youngest commercial fishers, scientists and managers must face working either with or despite F3-type fishers for perhaps 45 years longer than F1- or F2-type fishers in a cooperative arrangement. It is vital to work with them as much as any one opportunity allows, continually providing inclusive opportunities while allowing them to accrue and solidify their own FEK. As they continue to mature and succeed as commercial fishers, their experiences and motivations are likely to shift, as have those of F1 and F2 fishers. In the interim, it is important to not alienate these fishers or portray them unfairly. Like anyone working for themselves or starting off in their own business, F3-type fishers are protective of their own futures. As they represent a small segment of the overall commercial fishing community, a pragmatic approach may be warranted, biding time for them to more fully establish themselves before building longer-term partnerships.

Finally, F2-type fishers may represent the greatest potential partners for encouraging, developing, and enacting co-management approaches. Their fully-formed FEK is broad and has experienced competing viewpoints through participating in pubic hearings and program reviews. Their age and experience has brought them to a point where they can still envision ten or twenty more productive years, but they've already begun to envision the kind of fishery that they wish to bestow to their own children. In this research's F2 sample, these familial ties can be quite strong. Collected demographic data reports that twelve of the fifteen identified F2 fishers have immediate family working in St. Croix as fishers. This creates multiple, family-tied communities within the larger commercial fishing community, each with their own take on fishery-related issues and a sounding board that might be less appropriate in a more public setting. With family, incentives change. Most interviewed fishers would not try to "show up" a family member, nor would they allow themselves to fish in such a manner that they negatively impacted their relations' ability to support themselves and their families. Within the larger fishing community, such respect and responsibility, combined with a need to represent the fishing community leads F2-type fishers to be role models. As one F2 fisher explained their rationale for simultaneously questioning policy recommendations while remaining lawful:

> F2 fisher: I never got a fine for law-breaking. I don't break the rules. But it's so that they respect my word. If I was a person breaking the rules, they'd just say "whatever." (12 May 2010)

2.5 Conclusion

EBFM and research examining social-ecological systems have shown that classic, top-down regulatory systems are hindered by institutional inertia and an inability to develop adaptive strategies that results in delays in responses. Furthermore, fisheries that are collapsed or shifted to a new regime may never recover (Jennings and Polunin 1996). Managers might not recognize or respond to fisheries declines in time because of their own institutional limitations. Fishers, however, observe changes in real time as they make their daily trips. For co-management to succeed, regulatory programs must tap into FEK and fishers' ability to identify subtle changes in the fishery so that management can respond in a timely manner (Wilson, Raakjær, and Degnbol 2006; Begossi 2008; Silvano and Valbo-Jørgensen 2008; McCluskey and Lewison 2009). This embrace of FEK elevates participating fishers into positions of authority and respect, in the process validating their views, and placing them alongside scientists and managers.

Such a situation can be seen in St. Croix, where local management remains tied to CFMC programs, data, and direction. Yet, within this institutional arrangement, Magnuson-Stevens directly encourages the development and full participation of fishing communities in fisheries management, thereby offering an alternative, localized co-management approach. This research has shown that there is a range of views within a commercial fishing community and that this range can be revealed utilizing Q and an iterative analytical process using interviews, surveys and demographic data. Q, in fisheries management, can be a valuable tool for identifying outstanding issues and establishing which priorities give co-management the chance to succeed.

While this research demonstrates that quantifying biases within a fishing community can identify those individuals that might be most readily approached to develop co-management strategies, the primary value of Q is not to recognize which individuals to include or exclude from cooperative partnerships. Nor should Q be used in such a capriciously and obviously discriminatory manner, as those most opposed to management may have legitimate positions or concerns. Instead, examining fishers' biases should be used to identify common ground where partnerships may already exist between fishers and managers, and review how regulations can be amended to address fisher views while increasing support and compliance. Applying Q in a rigorous and reflexive manner, the issues that are most pressing to fishers can be identified, including determining which issues can and cannot be addressed in the short-term. Q can also be refocused onto managers, scientists, and policy makers to compare against fishers.

In this research, Q and additional supporting information from interviews and surveys revealed that fishers in St. Croix are strongly opposed to area-based management strategies, particularly because they felt that they were excluded from the process with past area closures like Buck Island. On the other hand, improving monitoring, relevant fisheries data collection, and enforcement mechanisms may be the clearest way to demonstrate to commercial fishers that a good-faith effort at partnering and supporting law-abiding fishers is underway. Such efforts are already being made in St. Croix, with managers working to improve upon the quality and timeliness of St. Croix-based fisheries data, which relies heavily on accurate monthly landings data provided by licensed fishers as a condition of their fishing license. Research programs that rely upon fishers in an equitable partnership have also been successfully carried out, demonstrating that fishers and scientists can work together and improve fishery resource understanding by combining FEK with scientific approaches.

The need to manage fisheries sustainably is a major challenge. Management failures over the past several decades highlight the need for a new approach. Co-management aims to meld the strengths of science and fishers via their FEK, to create new mechanisms that reflect the social and ecological benefits of marine resources. In tailoring such mechanisms to the realities faced within any fishery, the important first step to building these cooperative partnerships is identifying common ground and issues critical to other partners. Finding success in these areas can strengthen relationships between fishers and managers, so that more difficult issues may then be addressed in an open and respectful manner.

For fisheries to be sustainable natural resources, managers and policy makers must recognize the value of fishers' perspectives and be unafraid to employ their FEK in a way that supports social and ecological goals within a holistic, EBFM approach. Fishers already understand that the window to respond and implement management plans that encourage sustainable use while simultaneously moving to protect marine systems from a range of human and natural threats is small. The time has come for the adaptive co-management of fisheries.

CHAPTER III
USING A COUPLED BEHAVIOR-ECONOMIC MODEL TO REDUCE UNCERTAINTY AND IMPROVE FISHERIES MANAGEMENT AND RELATIONSHIPS IN A SMALL-SCALE FISHERY

3.1 Introduction

3.1.1 The Role of Uncertainty in Ecosystem-Based Fisheries Management

Fisheries have long been accepted to be poorly understood systems from both socioeconomic (Ross 1896; Gordon 1954; Wilson 1982; Fulton et al. 2011) and ecological (Hilborn 1992; Roberts 1997; Crowder et al. 2000; Hilborn 2002; Gaines et al. 2010; Hobday et al. 2011) perspectives. This combined socioeconomic-ecological 'system uncertainty' forms motivation behind efforts to develop and successfully implement ecosystem-based fisheries management (EBFM). EBFM approaches fisheries management holistically and with the goal of maintaining “ecosystem quality and sustaining associated benefits” (Brodziak and Link 2002, 589), including the benefits of fishing.

EBFM recognizes that system uncertainty will remain an important consideration going into the future (Murawski 2007), but proposed solutions to overcoming or implementing management plans despite uncertainty range from an extremely conservative approach guided by scientific assessments and monitoring (Jennings 2005) to "data-less" management (Johannes 1998). Yet, this recognition that fisheries and marine ecosystems retain a great amount of uncertainty has not prevented managers from attempting to 'fine tune' regulations and exploitation rates, often exacerbating the issue (Schrank 2007, 299). Working with, or despite, an incomplete understanding of a fishery remains the reality. The deliberate pace required to design and implement scientifically-rigorous benchmarks to quantify a fishery will continue to be at odds with the rapidity that marine systems are altered by natural and human- forces (Worm et al. 2006; Paddack et al. 2009), particularly commercial fishing (Pauly et al. 1998; Mullon, Fréon, and Cury 2005).

When regulatory failures occur, they are commonly discussed in terms of their inability to overcome system uncertainty (Botsford, Castilla, and Peterson 1997; Fulton et al. 2011), and that success will be found by developing a fuller ecological understanding. Yet, owing to political and economic realities, fisheries managers tend to prefer incrementally adjusting regulations rather than making large adjustments that are unenforceable, untenable, or endanger livelihoods. Under such factors, the ecological functionality of the fishery remains at risk and further declines can be anticipated, necessitating yet more reviews and regulatory adjustments.

As an alternative, managers can opt to manage a fishery with a limited understanding, preferring some management to no management at all. For such data-poor fisheries, it is necessary to adopt a 'precautionary approach' (Hilborn and Peterman 1996; Myers and Mertz 1998), which seeks to proceed with fisheries management in a conservative manner. When there is a nearly complete lack of understanding on fishery processes and system functionality, the precautionary approach recognizes that an unexploited, unperturbed ecosystem represents an ideal goal. EBFM attempts to preserve or recreate this ideal, with management of both socioeconomic and ecological outcomes being considered in concert within the recognized constraints imposed by system uncertainty.

3.1.2 Examining Fisheries Management through Fishers' Ecological Knowledge and Behavior

While scientists and managers grapple with system uncertainty, fishers have long embraced it and prospered, albeit from a much different perspective. Through fishers' ecological knowledge, or FEK (Johannes, Freeman, and Hamilton 2000), ecological uncertainties are addressed by fishers by a wealth of situational knowledge and experience, which in turn guides them to tailor their fishing effort to reduce their more pressing socioeconomic worries. To fishers, so long as their effort is not wasted by insufficient catch and operational costs are met, remaining uncertainties or unexpected outcomes are waved away by fishers as matters of luck or insufficient experience. Fishers tolerate and succeed in fisheries despite system uncertainty each day.

On the other hand, researchers and managers do not fare nearly as well in accepting uncertainty, as the goal of developing and ensuring a sustainable fishery is a profoundly different objective than being an efficient and productive fisher. Unlike fishers, fisheries managers are publicly accountable for their actions in the face of uncertainty. This reality leads to a reliance whereby actions are only taken when an abundance of supporting data has been collected (Rosenberg 2007). The time required to collect, interpret, and disseminate this data is great and is often a dated reflection of the state of the fishery (e.g. Weninger and Waters 2003).

Uncertainty about fish reproduction and larval dispersal, habitat selection, daily and seasonal movements and migrations all affect already complex fisheries models (Lockwood, Hastings, and Botsford 2002; Halpern et al. 2006; Pittman et al. 2007). EBFM energy is devoted to removing these remaining elements of uncertainty as a means of reducing risk. Yet through it all, fisheries managers recognize that ensuring ecosystem functionality is only half of the issue. There remains the question of how best to understand and manage fisher behavior and decision-making (Hilborn 2007b). This, rather than any ecological concern, forms the rationale for fisheries regulations, even if the goal is improved ecological functionality and resilience.

For fishers who remain engaged in the fishery following the establishment of regulations, their ability to remain profitable requires them to add regulatory impacts to their decision-making process. While this is applicable at all scales of fishing effort, it is a particular concern in small-scale fisheries (SSFs), where fishing effort already varies in how FEK directs fishing effort in response to daily weather and sea conditions, changes in stock distribution from behavior or water conditions, and market trends. When regulations prevent SSF fishers from targeting certain stocks or areas, they can opt for three different strategies: 1) they can redirect and increase their effort toward other stocks or areas in an effort to recoup anticipated losses associated with the regulation; 2) they can maintain their effort, accepting losses associated with regulations with the understanding that they can be recouped at a later date or are just part of being a fisher; or 3) they can ignore regulations and continue to fish as before while making adjustments in selling their catch so as not to draw notice. These choices are likely revisited periodically both at the level of each fisher and also within a larger community dynamic, leading to a range of behaviors at both the individual and fishing fleet level, thereby building behavioral uncertainty. Interestingly, these options, here being introduced in relation to fisheries management, are as relevant to other decisions fishers must make in the face of other physical and market forces. However fishers decide each day, their decision affects not only their own livelihood, but also the fishery as a whole.

3.1.3 Small-Scale Fisheries, Uncertainty, and the Development of Locally-Appropriate Regulations

Small-scale fisheries represent a unique scale of commercial fishery exploitation. SSFs are characterized by a small fishing fleet and numbers of fishers, relatively low capital investments, and small spatial concentration of directed effort compared to large-scale, industrialized fishing. SSFs target specific grounds known within the fishing community in an opportunistic manner, harvesting several different species with several gear types each trip (Béné and Tewfik 2001; Berkes et al. 2001b; Berkes 2003). SSFs are also highly uncertain systems.

Many SSFs are hampered by poor data collection and monitoring, a situation often exacerbated by sparse public and private funds, local dependency on fishery resources for food and livelihood against a relatively stark economic reality, and a dearth of effective management and enforcement (Béné 2009; Bentley and Stokes 2009; Cochrane, Andrew, and Parma 2011). These recognitions that any SSF is likely 'data-poor' (Berkes et al. 2001b; Garcia and Cochrane 2005; Béné 2009), greatly increase the complexity of their management. Without such data to reduce system uncertainty even incrementally, conventional gear-selection or single-species management approaches are not likely to be effective (Wilson 2006). Instead, SSFs may be better managed by recognizing that FEK provides a locally relevant foundation that reduces those elements of system uncertainty considered important to fishers. Understanding FEK means understanding the local perspectives of the fishery's ecology and socioeconomics, and developing regulations that reflect this reality. In doing so, management would answer the call to “manage people, not fish” (Berkes et al. 2001b, 12).

FEK and fishing behaviors can be used to bridge the gaps in system uncertainty formed by a lack of scientific data. Even if only qualitative, FEK presents a fuller understanding of fishery functions, and can be used to begin the process of developing regulations that address the sustainability of exploited stocks. Such regulations, if designed inclusively with the participation of fishers, are also more likely to be supported by fishers as it reflects their perspectives, knowledge, and behaviors (Heyman 2011). Garnering this support is crucial, as fishers' FEK becomes the foundation of their own management, and without their support, the likelihood of management failure is considerably higher.

3.1.4 The Impact of Fishing Behavior Uncertainty on Regulations

The behavior and decision-making of fishers has historically been described as being based in “open-access”, profit-driven motivations (Gordon 1954; Hardin 1968; Wilen 1985; Holland and Ginter 2001). Simplifying the motivations of fishers into a simple economic context of constant fishing pressure, however, overlooks small-scale decision-making by fishers that, while economic in nature, have little visible evidence in day-to-day landings data. These decisions, however, may have large ecological impacts. Fishers will fish in such a manner as to maximize their catch per unit effort, or CPUE (Branch et al. 2006). For any fully exploited fishery, the larger the fishing ground the less dense the fishing effort. This recognition is critical particularly for SSFs, where fishers are geographically or politically unable to expand their grounds. To continue to succeed, SSF fishers rely on their FEK and wealth of experience to recognize and exploit particularly productive areas against a larger, more uniform backdrop of seemingly similar habitats and conditions. Experienced fishers know where this patchiness leads to tremendous changes in stock densities at relatively small spatial scales. These fishers capitalize on this patchiness and maximize CPUE by only targeting the densest grounds, consciously avoiding many suboptimal areas.

As a result, the best grounds tend to be greatly preferred in a SSF. This preference can lead to short-duration overfishing. As production decreases, fishers will move to other areas where they feel confident that their CPUE will again be maximized. While in ocean-scale fisheries, this serial routine of intensely fishing a ground to exhaustion was mistakenly thought to be solved by “roving bandit” fleets moving further on to new, unexploited grounds and stocks (Berkes et al. 2006, 1557), the fear is that even at a scale of exploitation several factors lower, SSF grounds may also lack the resiliency to fully recover at necessarily short time periods, given the limited amount of alternative grounds before fishers return (Hutchings 2000; Russ and Alcala 2004; McClanahan et al. 2007).

Despite this sobering outlook, managers should continue to seek opportunities to allow exploited systems to recover. In the short-term, reducing effort remains a major regulatory component (e.g. CFMC 2010), particularly when managers assume that fishers always seek to maximize CPUE and therefore have a constant level of effort in targeting those fishing grounds that they consider most productive. This assumption, however, falls apart at small temporal and spatial scales, where effort is highly variable and affected by fishers’ ability to redirect effort in response to weather conditions, stock movement, seasonal effects, and regulations. These decisions blur evidence of regulatory success because the metric of fishing effort, considered to be static except in relative size, is a poor analogue in measuring a patchy fishery (Sanchirico and Wilen 1999), where fishing pressure matches ecological variability (Wilen et al. 2002).

A theoretical starting point for redressing this issue is for managers to understand that fisheries, from the perspective of fishers, remain economic institutions supported by ecological functions. As a result, while EBFM may indeed be the proper approach for identifying and pursuing long-term management goals, the immediate need to reduce exploitation and defend against the impacts of overfishing is more appropriately addressed by examining fishing behavior, which has a decidedly economic element.

Therefore, understanding fisher knowledge, experience, and behaviors, remains a wise place to begin examining fishery management (Johannes 1998; Johannes, Freeman, and Hamilton 2000; Armitage et al. 2009), such that some uncertainty that cannot be addressed through scientific methods can be qualitatively described by fishers. Fisher behaviors and their FEK reflect an instantaneous picture of the state of a fishery at a particular moment in time. As such, these behaviors tie fishers' economic motivations to ecological impacts on the fishery's health and sustainability. From here, locally relevant regulations can be developed. For SSFs, where economic hardships always appear to just around the corner and few alternatives exist to replace lost income of fishers, it is imperative that managers do not develop vituperative regulations, but instead remain acutely aware of potential impacts of any such mechanism on livelihoods and local food demands and work to offset any necessary impacts by engaging and working with affected fishers to develop suitable management alternatives that encourage compliance and allow for stock recovery.

3.1.5 Modeling Fishing Behaviors to Quantify Regulatory Effects

Though much has been made about the limitations of conventional fisheries regulations formed by economic theories (Lauck et al. 1998; Clark 2006a; Beddington, Agnew, and Clark 2007), it remains important to recognize how economic forces affect of fishing behavior. Bioeconomic theory suggests that, for small-scale fisheries, effort will reduce the fishery to a level of economic replacement, that is, the value of a fisher's catch will only just exceed the costs associated with fishing (Gordon 1954), often identified by the "Open-Access Equilibrium", or OAE (Clark 2006b). For any profitable fishery, effort will continue to increase through the addition of more fishers, the employment of more efficient gears, or an increase in sea-time for any one fisher until the OAE is reached. This effort increase reduces resource rents and the eliminates the opportunity for individual profit (Clark 1985). Effort above the OAE becomes unprofitable, leading to fishers being unable to cover costs, forcing them to either increase efficiency or depart the fishery. In the case of SSFs, particularly in parts of the world where economic alternatives are rare or considered inaccessible for fishers to enter, increasing efficiency remains the primary response, which increases the risk of overfishing and stock decline (Mullon, Fréon, and Cury 2005).

As Mullon et al. (2005) point out, improved fishing efficiency is not always easily identified, nor is every improvement in efficiency deleterious from an ecological perspective. Yet, every economic decision a fisher makes can be immediately tied to an ecological impact. These decisions are not based at random, but on the collected experiences and knowledge that form their FEK, which in turn, reflect a unique perspective of the ecological state of a marine system as a fishery resource. In this manner, fishing behavior becomes far more certain, predictable, and therefore manageable. And given the trepidation that researchers and managers have in working with uncertainty, this approach can form the basis of long-term management goals through a series of short-term responses.

3.1.6 The Need for Adaptive Regulatory Capacity Despite Uncertainty in Data-Poor Fisheries

The methods for examining ecological functions within a fishery are robust if not yet broadly used (Allison and Ellis 2001; Botsford, Micheli, and Hastings 2003; Roberts et al. 2003). Studies such as these continue to reveal long-term trends and in the process, incrementally reduce system uncertainty. Yet, for management to begin reducing or reversing stock declines, another parallel approach that focuses on the scale and perspective of the fisher is needed. This complementary approach is vital for developing appropriate management plans as fisher behavior remains the primary link between the ecology and economics of fishing (Branch et al. 2006; Abernethy et al. 2007; Hilborn 2007b; Fulton et al. 2011). Indeed, understanding fisher decision-making and fleet behavior can be a fruitful management pursuit (Fenichel et al. 2008; McCluskey and Lewison 2009), even in a qualitative, data-poor setting (Bentley and Stokes 2009; Dambacher et al. 2009). From economically motivated decisions made by fishers to remain efficient, researchers can glean their FEK, which, in turn, provides a statement on the current ecological health of the fishery.

The purpose of this paper is to present the findings of one such examination linking FEK and regulatory mechanisms to fishing effort in a tropical nearshore reef-fish SSF in the United States Virgin Islands managed partially through the use of seasonal no-take MPAs. For a SSF, fishers will tend to select those grounds that they believe are the most productive, unless conditions or regulations prevent fishing there. By examining physical, market, and regulatory forces in concert, this research develops a probability model that predicts the likelihood that, given a certain suite of conditions, a fisher will likely target those preferred grounds. An accompanying economics model estimates the value of fishing those grounds and potential forfeitures that fishers may suffer from closing the grounds either seasonally or permanently. This coupled behavior-economics model suite can then be used to identify where regulatory conflict might arise, if forfeitures are large enough to encourage illegal fishing, or if those anticipated losses could be partially remediated by fishing other productive grounds. Finally, the model suite can be used in a reflexive manner to examine its own usefulness in managing fishing effort and maintaining sustainable stocks.

3.2 Site Description

The study was conducted in St. Croix, United States Virgin Islands. St. Croix's nearshore habitat can be described as a mixed reef system, with fringing and spur-and-groove coral reefs interspersed with areas of seagrass and sandy bottoms (NOAA 2008). A small-scale commercial fishery employs approximately 200 fishers (Kojis 2004), landing approximately 550,000 kg yearly (Figure 3-1), nearly all of which is consumed locally. The fishers are opportunistic, targeting multiple species with several different types of gear on any particular day. Unique for U.S. Caribbean waters, the majority of St. Croix fishers utilize scuba gear to aid in fishing, although other traditional gear types, particularly hand lines and weighted traps, are also employed. Commercial fishers target at least forty different nearshore stocks, dominated by three families of demersal fishes

(Families Scaridae (wrasse and parrotfish), Lutjanidae (snapper), and Serranidae (grouper)), queen conch (*Strombus gigas*), and Caribbean spiny lobster (*Panulirus argus*). Scarids in particular represent nearly 33% of total landings by weight.

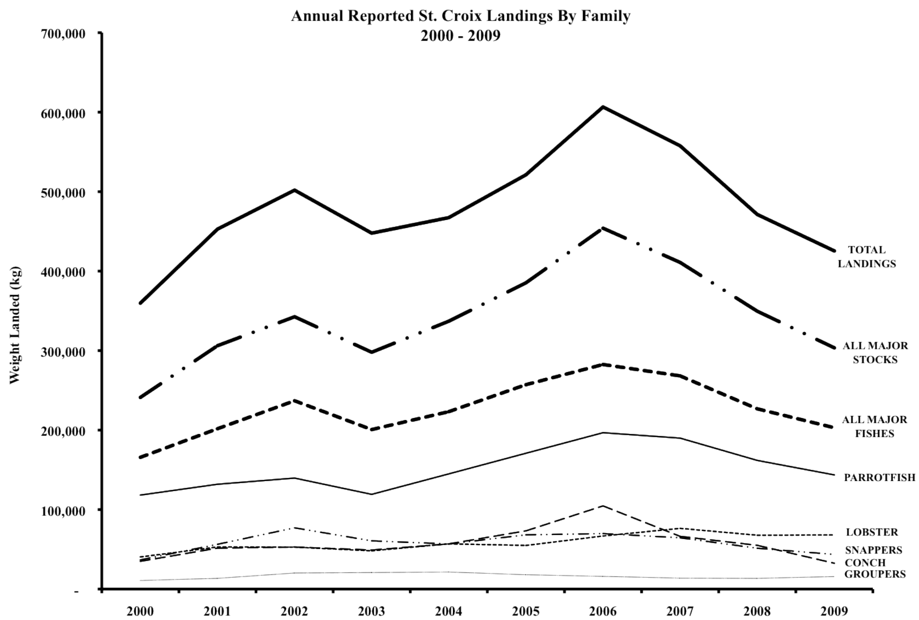


Figure 3-1. Annual St. Croix landings of major stocks, by family, 2000 – 2009.

St. Croix fisheries management includes two permanent no-take closures and two seasonal no-take marine protected areas (MPAs). The two permanent closures are Buck Island National Marine Refuge and Salt River Bay National Historic Park and Ecological Preserve. Although both fall completely inside territorial waters, they are managed through the National Park Service as federally protected lands and waters. Prohibitions on fishing are only one aspect of a much larger mandate to protect and preserve natural, historical, and cultural resources inside both parks. The first seasonal no-take MPA, the Red Hind Spawning Aggregation Area (RHSAA), is located wholly in federal waters along the eastern terminus of Lang Bank. This MPA provides protection for a spawning aggregation site of red hind (*Epinephelus guttatus*), and prohibits fishing there from 1 December – 28 February (NMFS 2008; DPNR 2009; NMFS 2011), during the red hind's peak spawning period (Nemeth et al. 2007). The second MPA, the Mutton Snapper Spawning Aggregation Area (MSSAA), protects a known spawning aggregation site for mutton snapper (*Lutjanus analis*) from 1 March – 30 June along the edge of St. Croix's southwestern bank (NMFS 2008; DPNR 2009; NMFS 2011), and straddles federal and territorial waters (Figure 3-1). The MSSAA was first established in 1993 (58 FR 53145).

From 1 April – 30 June, a no-possession regulation is in place in all EEZ waters for mutton snapper, effectively creating a fully-closed season in the U.S. Virgin Islands. Several other fishes also receive seasonal no-possession prohibitions: red grouper (*Epinephelus morio*), yellowedge grouper (*E. flavolimbatus*), black grouper (*Mycteroperca bonaci*), yellowfin grouper (*M. venenosa*), and tiger grouper (*M. tigris*) from 1 February – 30 April; vermilion snapper (*Rhomboplites aurorubens*), black snapper (*Apsilus dentatus*), blackfin snapper (*Lutjanus buccanella*), and silk snapper (*L. vivanus*) from 1 October – 31 December; and lane snapper (*L. synagris*), which coincides with the aforementioned 1 April – 30 June prohibition on mutton snapper. Both Nassau grouper (*Epinephelus striatus*) and goliath grouper (*E. itajara*) are considered endangered species and their harvest or possession is prohibited throughout the year in both territorial and federal waters (NMFS 2008, 2011). Spiny lobster is managed via a minimum size limit, a 3.5-inch (8.9 cm) carapace length, as well as prohibitions against keeping 'berried' females or removing their eggs.

Queen conch is managed via a series of daily and seasonal quotas within a sliding open season that begins in both territorial waters on 1 November. Each commercial fishing vessel can collect 200 conch per day in territorial waters, while the federal bag limit for commercial fishers is 150 conch per day per fisher, rather than vessel. For St. Croix, reaching the territory's 50,000 pound (22,680 kg) annual quota sets off a no-possession regulation and closes the season (DPNR 2009). Interestingly, the no-possession regulation does not apply to conch caught, cleaned, and stored during the open season, meaning that those conch can be sold throughout the closed season (12 VIC § 316). The current federal regulations establish a closed season from 1 July – 30 September each year. As the 2011 – 2012 conch season began, a major public hearing effort has led to federal fishery managers issuing new federal rules that, although technically affecting fishing only in the Caribbean EEZ (NOAA 2011), harmonize federal regulations with territorial regulations, may lead to a more even management of conch stocks in both the federal and territorial waters of St. Croix.

Overriding these management instruments, St. Croix's fishery operates within several other regulatory and market forces that dictate supply-and-demand trends. The queen conch fishery operates throughout the winter months and towards May, until the 50,000-lbs. quota is reached, which initiates a fishery closure until the following November. This period reflects the "high season" for Crucian fishers, given the relative increase in demand for high-value stocks like conch ($7 per pound), spiny lobster ($8 per pound), dolphinfish (*Coryphaena hippurus*) and other pelagic species ($6 per pound), and snappers and groupers ($6 per pound). After the conch season closes, the "low season" begins, characterized by less frequent fishing trips by commercial fishers, smaller landings by weight, decreased demand for fish generally and a transition to a much more generalist approach, targeting a range of smaller demersal fish families commonly referred to as "potfish" or "bluefish". These demersals, which collectively cost $4 per pound include parrotfishes, grunts, squirrelfishes, coneys, surgeonfishes, and boxfishes. This time of year also runs the increased risk of hurricanes, which can disrupt fishing activities through storm-generated waves, high winds, and changes in currents and water conditions.

Fishers use small (6.3 ± 1.6 m) open-cockpit fishing vessels (Kojis 2004), and launch from three major locations around St. Croix. The selection of where to launch from is a reflection of the their FEK and is determined each morning depending on where the fisher intends to fish, what stocks they are targeting that day, weather conditions, and regulatory forces, including area and seasonal closures. Once returning to the island, fishers set up roadside markets at well-known, permanent locations. While most fishers operate independently, several fishers share a few market locations. The largest of these markets is located in Estate Villa La Reine on the previous site of a permanent, government-provided open-air fish market condemned in 2005 (Figure 3-1). The La Reine market is centrally located in the interior of the island, and is open Monday through Saturday, beginning at 6am. Demand typically increases through the week, with several fishers opting to not fish on many Mondays. Saturdays are the island's market day, with many bustling roadside stands appearing only for that day. At La Reine, the fish market shares space with a permanent, government-built and maintained farmer's market, which acts as an additional customer draw.

3.3 Methodology

3.3.1 Weather Data Analysis

Wind direction, speed, sea direction, and sea height data were compiled from 21 January – 3 September 2010, from NOAA's National Data Buoy at Salt River (Station SRBV3). The original data files produced a wind measurement every six minutes while the wave data reported a measurement every thirty minutes, barring instrument or data transfer failure. Data was filtered to exclude failures and then hourly means were calculated and sorted by week, with each week beginning on a Friday to coincide with an increased fishing effort ahead of the traditional Saturday market day on island. Wind strength, direction, and frequency of direction was plotted in wind compass plots using MatLab software (MatLab v7.0). Wind speed data were grouped into 4 m/s bins and wind direction data was grouped into 36º bins, with the first bin beginning at true north (0º) and proceeding clockwise. Frequency of wind direction for each directional bin was plotted on concentric rings extending outward. Wave heights were grouped into bins of 0.55 m for the development of economic regression models based on wave height. Descriptive statistics, including mean (μ) and standard deviation (σ) were calculated.

The selection of aggregating wind and wave data into bins was purposeful. St. Croix is largely protected from open seas on both its north and eastern exposures. The Windward Islands chain ends at the island of Anguilla, at a distance and bearing of 161 km and 67º from St. Croix. North of Anguilla, an open area of the Atlantic Ocean can enter into the Caribbean Sea between Anguilla and the British Virgin Islands, which lie approximately 32º and 110 km from St. Croix. The 36º bin, which reflects compass bearings from the Christiansted Harbor buoy station, provides a unique set (compass bearings of 36 – 72º) that covers the majority of this open-water area where wind fetch is much greater, therefore increasing the likelihood of deteriorating sea conditions due to storms originating from those headings. Given St. Croix's eastward extending Lang Bank, the angle of unimpeded Atlantic Ocean seas and winds begins at roughly 20º and 90 km from the eastern terminus of the British Virgin Islands shelf.

The wind speed bin of 4 m/s is based on calculations of the mean wind speed from the Christiansted Harbor buoy data (4.1 ± 2.0 m/s), which establishes a bin at 8 m/s (15.5 knots), approximately +2σ above the mean wind speed, which corresponds to an F5 on the Beaufort Scale, signaling the development of white caps and wind-driven water. In similar fashion, the mean wave height (0.81 ± 0.29 m) provides a break at +1σ (1.1 m). In interviews, wave heights above one meter concerned fishers. They describe increasingly unsafe conditions in strengthening seas, particularly during the conch season. Regulations require them to land conch whole and in shell (DPNR 2009), resulting in laden vessels with several piles of sharp-edged conch shells taking up space while adding several hundred pounds of weight. Additionally, vessel captains often rely on small trailing surface buoys or scuba bubbles to track their fishers when they are in the water, and both strong winds and heavy seas can make this task difficult and dangerous. To correlate landings data with daily weather conditions, records from six hours prior to local sunrise to 13:00 local time were separated, and then processed to determine a morning average which represented those conditions first encountered by fishers as they prepared their boat and gear to fish each day.

Fully 12% of daily records, as correlated to market records, exceeded the threshold bins for wind speed and wave height. This percentage, in terms of event frequencies, reflects a likely occurrence of 3.6 events per month, or approximately once weekly. Such a frequency is enough to be a factor in each fisher's decision-making process. A lower threshold standard deviation, such as +0.5σ, would flag events with an expected occurrence of at least twice weekly, which would negate the statistical power to events and conditions fishers regularly encounter. A higher threshold reduces unusual events to an expected frequency of once every three weeks or more, which is too severe a threshold to be useful for this work. Therefore, the 8-m/s ($\mu + 2\sigma$) wind speed threshold and 1.1-m ($\mu + 1\sigma$) threshold for wave height, identifies days where deteriorating sea conditions that would likely make fishing difficult yet still commercially necessary, given that most commercial fishers on St. Croix fish 3 – 4 days per week (Kojis 2004). If fishers were to generally avoid fishing in conditions described by this threshold, they would forfeit a week's income each month.

Weather data was further aggregated into "severe'" or "calm" conditions. Severe weather was defined to be a summed value of 2 or 3, based on the dummy values for wind speed, wave height, and reported rainfall. Therefore, any severe weather day reported at least two of the following: unusually high winds, sea height, or rainfall. Fishing destination choices were then divided into four conditional situations: 1) fishing grounds selected during extended calm weather conditions; 2) fishing grounds selected one or two days before severe weather arrived; 3) fishing grounds selected during severe weather conditions, and; 4) fishing grounds selected one to two days into calm weather conditions following severe weather conditions.

3.3.2 Landings and Market Sampling

Landings and market sampling (n = 427 market stall samples) was conducted primarily at the La Reine fish market (n = 357 market stall samples) as fishers arrived. Four separate roadside stands (n = 70 market stall samples) were also visited throughout the research period. Sampling began on 21 January 2010, and concluded on 3 September 2010, a period of 225 days. Prior to being included into the sample population, each fishing operation was approached and the research aims were presented. Participating operations, their owners, captains, sellers, boat hands, and other associated fishers gave verbal and written approval, and their presentation in this paper follows established institutional standards, including ensuring their anonymity. For each fishing operation on each day of observation, the weight of total landings was estimated, grouped by demersal fishes, conch, and lobster. Value of landed catch was then calculated based on established market prices: $4 per pound of demersal fish, $7 per pound for knocked and cleaned conch meat (in $20 bags), and $8 per pound for spiny lobster. These prices remained stable throughout the research period. Values calculated for demersal fish represent low-end estimations, as commercial fishers sell both $4 potfish and $6 reef fish throughout the year, with some even selling 'mixed bags' at $5 per pound. This study did not directly record sales to restaurants, hotels, and other large-volume buyers that never pass through the public market. Researchers interviewed fishers on any direct sales, and added them to the market sample when they provided figures. If none were provided or fishers declined to respond, it was assumed that the operation had no direct sales that day.

Fourteen landings censuses were conducted opportunistically, to verify landings estimations. These censuses calculated the upper range for daily, scuba-assisted catch per fishing operation to be 122 ± 26 demersal fishes, weighing 106 ± 18 lbs. (49.0 ± 8.2 kg). Lobsters were individually weighed when possible. Otherwise total weight was estimated based off the mean calculated weight from all measured individuals of 2.4 ± .4 lbs. (1.1 ± 0.2 kg). This weight is similar to a reported mean weight of 2.58 lbs. (1.2 kg) by Castillo-Barahona (1981). Simultaneous records were kept detailing running sales totals, and were incorporated into the final value determination for observed operations as a correcting factor, particularly when higher-value fishes were the primary sale.

Fishing grounds selection data was collected by interviewing fishers as they either departed a particular launch site in the morning, returned to the launch site, or once they reached the market. Fishing grounds were demarcated from existing maps (DPNR 2005b; Valiulis and Messineo 2005). From the interviews, five major grounds were identified (from east to west): Lang Bank, Point Udall and northeast St. Croix, Grassy Point, Ha'Penny Bay, and the Southwestern Bank (Figure 3-1). In interviews, fishers described Lang Bank being the most productive and therefore preferred St. Croix fishing ground. Fishing ground selections were aggregated by site and date for frequency analysis to examine changes in site selection behavior as functions of daily physical conditions on one hand and regulatory conditions on the other.

While La Reine fishers prefer the five grounds, they do not represent the full range of reef-fish fishing grounds for St. Croix. Fishers living near the west end of the island often launch from the town of Frederiksted, and commonly fish on the western end of Sandy Point and the western fringing reef and shelf. Few fishers spend much time along the northern shelf, given its narrowness, its popularity as a tourist draw, and the presence of area closures at both Salt River and Buck Island. Most of the fishing that occurs along the northern shelf occurs in the nearshore, territorial waters east of the city of Christiansted, between St. Croix and Buck Island. The East End Marine Park, a territorial marine multiple-use park where park-specific fishery regulations are still being developed, encompasses much of these grounds. For purposes of this research, these popular conch and demersal fish grounds were included into the Pt. Udall and northeast St. Croix grounds.

For each of the five selected grounds, recorded landings data were separated and presented as a function of seasonal regulatory conditions (Table 3-1). A two-tailed, two-sample t-test was completed on each presented dataset to identify any significant difference in expected values ($p \leq 0.05$) in comparison to Lang Bank recorded landings.

3.3.3 Development of Regression Model of Predicted Grounds Selection by Conditions

To evaluate the relative effects of various conditions on the choice of fishing at Lang Bank, a multiple variable, binomial logistic regression model was built. The final model tested physical condition variables (mean wind speed and direction, wave height, rainfall), market behavior conditions (weekday trips, conch collection, lobster collection), and regulatory conditions (open conch season, RHSAA closed season, MSSAA closed season). Model testing included both original data and data re-coded into binary form [0,1] for calm weather conditions below threshold bins for wind speed ($v_w \leq$ 8.0 m/s) and wave height ($v_v \leq 1.1$ m), and the predominant wind direction (72 - 144º).

Table 3-1 Fishing Trips Recorded to Targeted Grounds, by Season and Regulations (* Significant at $p \leq 0.05$, two-tailed t-test compares grounds to Lang Bank)

		Lang Bank	Pt. Udall	Grassy Pt.	Ha'Penny	Southwest
Conch Season Open	1 Jan – 28 Feb (RHSAA Closure) n = 19 days sampled	44	17 (0.005)*	5 (0.000)*	0 --	10 (0.000)*
Conch Season Open	1 Mar – 30 Apr (MSSAA Closure) n = 22 days sampled	24	16 (0.22)	10 (0.026)*	1 --	22 (0.81)
Conch Season Closed	1 May – 30 June (MSSAA Closure) n = 24 days sampled	56	32 (0.016)*	30 (0.005)*	5 (0.000)*	4 (0.000)*
Conch Season Closed	1 July – 10 Sep n = 30 days sampled	49	26 (0.029)*	16 (0.002)*	10 (0.000)*	50 (0.93)

Original data records and test variables were used to create a predictive model on whether a fisher would opt to fish at Lang Bank. Following preliminary tests of model fit with statistical software (SPSS v17.0) a logistic binomial linear regression model was selected, following the form:

$$(1) \quad f(z) = \frac{1}{1+e^{-z}}$$

where $f(z)$ is the logistic probability that a fisher will either not select $f(z) \approx 0$ or select $f(z) \approx 1$ to fish at Lang Bank on any given day, given a set of physical, behavioral, and regulatory conditions. This probability is built on a summation of the log-odds variable z. The variable z is composed of odds ratio coefficients β and explanatory variables x, such that:

(2) $z = \beta_1 x_1 + \beta_2 x_2 + \ldots \beta_i x_i$

where variables of x represent physical, behavioral, or regulatory conditions identified in a step-wise process to be significant in explaining the predictive strength of the model. The model was run for all combined records. Interactive variables for weather conditions were developed and also tested. For each model iteration, each step-wise addition of a variable resulted in a percent change in predictive ability. Coefficients with significant values ($p \leq 0.05$) were kept and the final model was tested for goodness-of-fit (Hosmer-Lemeshow Test; HL ≥ 0.05). The final model is reported, including Nagelkerke's pseudo-r^2 value, and predictive strength along the continuum zero to one. From this model, each fisher was then separately tested using the same explanatory variables.

3.3.4 Development of Economic Model of Expected Landings Value by Grounds

The grounds selected by fishers and market values calculated were used to develop an economic model predicting daily landed value by fishing operation, based on physical, behavioral, and regulatory conditions. Records were identified by operation, fishing grounds selected, and recorded market landings and then assembled into a larger dataset for model development (SPSS v17.0). Variables were tested for normality, covariance, and heteroskedasticity, resulting in the selection of two weather-related, one behavior-related, and three regulatory-related binomial variables: 1) calm winds; 2) calm wave heights; 3) targeting Lang Bank; 4) the RHSAA closure; 5) the MSSAA closure; and 6) the open conch season. The model takes the form:

(3) $V = f(v, w, x)$

where predicted value of landed stock (V) is function of weather conditions (v), fisher-dependent behaviors conditions (w), and regulatory conditions (x). Following tests of model fit, a standard linear model was selected, taking the form:

(4) $$V = \sum_{i=1}^{i} \beta_i v_i + \sum_{j=1}^{j} \beta_j w_j + \sum_{k=1}^{k} \beta_k x_k$$

As predicted values represent gross value of landed catch, the linear model is forced through the origin ($\beta_0 = 0$), representing the fact that a fisher cannot possess a landed value if they opt not to fish. Regression coefficients (β) were calculated for three conditional variables *v, w,* and *x*. Two-tailed t-tests ($p \leq 0.05$) were reported for each coefficient value.

3.4 Results

3.4.1 Weather Condition Analysis

The wind dataset had 4,715 data points, beginning at 0:00 AST (-4:00 GMT) on 21 January 2010 and ending at 23:00 AST on 3 September 2010. Over this period, mean wind direction was 118 ± 41º, with a mean speed of 5.7 ± 2.5 m/s (11.1 ± 4.9 knots). This data supports the findings of Caselle and Warner (1996), which identified the southeastern shelf and coastline of St. Croix to be the windward side of the island. Fully 55% of winds arriving to St. Croix originate from a generally east-southeasterly direction (72 – 144º), and when incorporating all "windward" bins (72 – 180º), this frequency rises to nearly 70% (Figure 3-2).

Figure 3-3 presents gross value in landings by targeted fishing grounds for the range of weather conditions: calm, pre-severe, post-severe, and during severe weather conditions, as defined by the methodology. In periods of extended calm weather, landings at Lang Bank were significantly higher than any other targeted grounds, with a mean catch (± 1.5 standard deviations) of $518 ± 296 (n = 99 trips). Interviewed fishers generally preferred fishing east of St. Croix, with Pt. Udall landings being the second highest ($396 ± 267, n = 45 trips). Under other conditions surrounding the arrival of severe weather, Lang Bank again landed significantly higher gross value of catch than other grounds, although for one to two days after severe weather ("Post-Severe Weather Conditions"), the Southwestern Bank was targeted and landed similar values worth of catch. In particular, the maximum recorded landings for Lang Bank and the Southwestern Bank were similar, suggesting that fishers with a stronger FEK for the Southwestern Bank could be as potentially successful as they could at Lang Bank, with the added benefit of lower operating costs because of the shorter distance traveled.

There are four general weather patterns in St. Croix: 1) the prevailing east-southeasterly winds that occur through much of the year; 2) the locally-named "Christmas Winds" that appear during winter months; 3) a period in the spring of unsettled air and tropical wave activity; and 4) the increased development and activity of tropical waves during the mid- to late-summer, including the development and threat of tropical storms and hurricanes. Passing winter storms generate the Christmas Winds, briefly shifting winds northward from their predominant east-southeasterly origin. Storms arriving from the east-northeast cross the open-water fetch between St. Croix, the

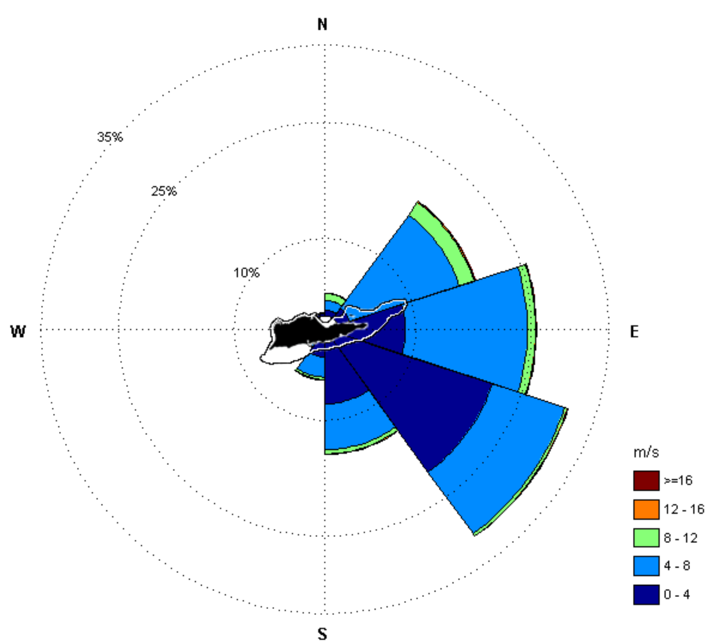


Figure 3-2. Mean wind speed (m/s), by direction, 21 January - 3 September 2010.

British Virgin Islands, and Anguilla. Although generally short-lived, with any storm lasting from a few hours to days, the Christmas Winds represent, apart from tropical storms, some of the harshest weather conditions from the perspective of fishers owing both to the wind strength and the seas these winds build. In 2010, these winds arrived 25 - 29 January. These winds averaged 8.9 ± 0.74 m/s (17.3 ± 1.4 knots), from a bearing range of 89.8 ± 31.4º. Wave heights during this time increased to 1.4 ± 0.2 m (4.6 ± 0.7 ft). All statistics were significant at $p \leq 0.05$ when compared to the surrounding ten days (21 – 24 January, 30 January – 5 February).

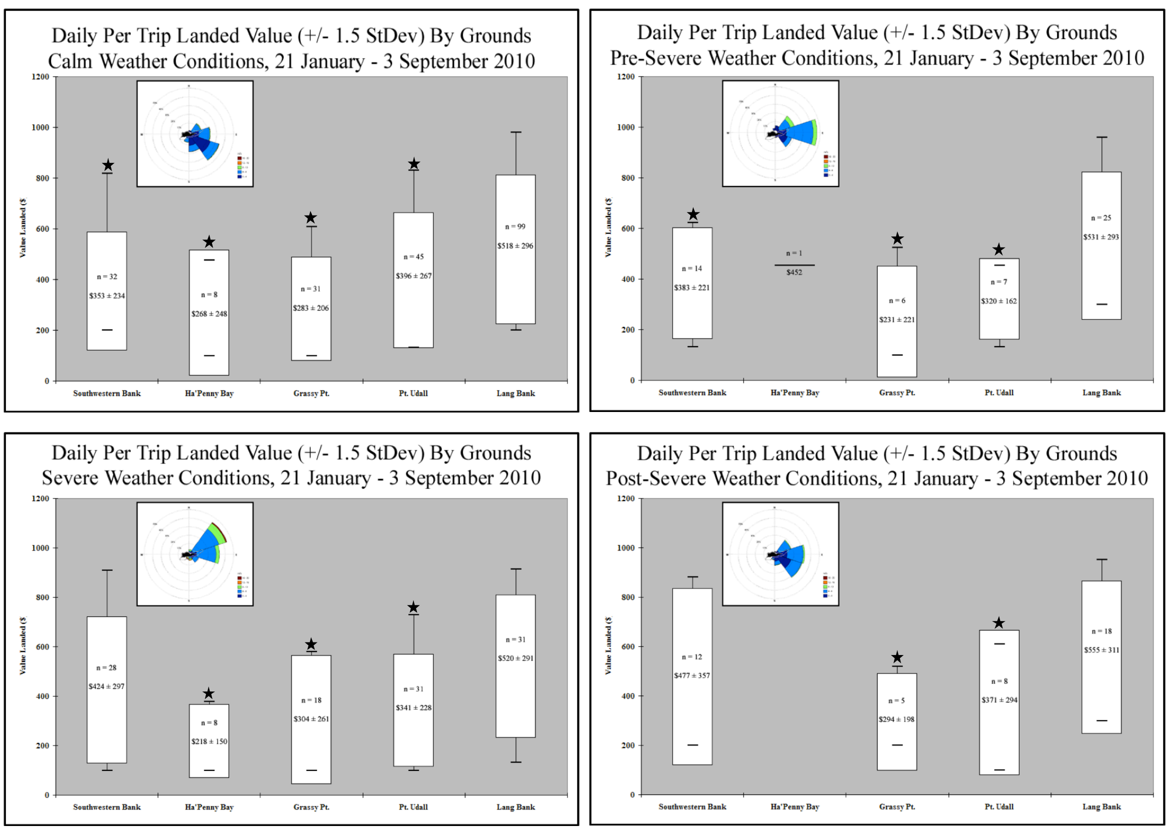


Figure 3-3. Daily per trip landings, by gross value and weather conditions. *(Stars reflect two-tailed t-test comparing daily landings from each grounds to Lang Bank, significant at $p \leq 0.05$; box plot represents +/- 1.5 Standard Deviations from Mean Gross Landed Value, with number of trips (n) and mean included inside box. Tails*

represent maximum and minimum recorded gross landing for each grounds.)

Unsettled weather continued through February and into April, with several extended periods of inclement weather and deteriorating conditions for fishing identified from 19 February through 22 April 2010. These storm events were statistically similar to the Christmas Winds, with a mean of 8.9 ± 0.65 m/s (17.3 ± 1.3 knots), bearing from 84.5 ± 31.2º. These winds were also significantly different in both speed and direction from non-storm winds during this period ($p \leq 0.05$). Similar unsettled systems appeared in mid-May (9.12 ± 0.83 m/s at 93.3 ± 10.8º) and 16 – 24 June (8.9 ± 0.76 m/s at 95.4 ± 11.6º). All told, these storms from January through June impacted 46 of the 95 observed fishing days. These included eleven days during the defined "pre-severe weather" conditions (3 days from 21 January – 30 April; 8 days from 1 May – 3 September), 24 days during the defined "severe" conditions (10 days from 21 January – 30 April ; 14 days from 1 May – 3 September), and 11 "post-severe weather" days (5 days from 21 January – 30 April; 6 days from 1 May – 3 September). Severe weather conditions were significant ($p \leq 0.05$) compared to all aggregated records from other categories.

One hurricane affected St. Croix over the course of the study period. Hurricane Earl, a Category 3 storm passed approximately 100 km to the north of St. Croix on 30 August 2010. Outer wall winds battered St. Croix with tropical force winds gusting to 95 km/h (51 knots), while Christiansted buoy recorded wave heights of 3.0 m above mean sea level, approaching the island from a bearing of 56º. Total recorded rainfall attributed to Earl in St. Croix was 13.9 cm. At the La Reine market, scuba-assisted fishers reported being unable to fish from 29 – 31 August (29 August was a Sunday), with only limited success on 1 September, citing turbid waters from both the storm activity and the resulting coastal flooding and transport of sediments into the ocean. In anticipation of Hurricane Earl, however, eight La Reine fishers brought in a exceptionally large Saturday market catch on 28 August, totaling nearly $4,200 in sales, compared against the 'low-season, no conch' total sales average for La Reine of $1892 ± 1061, and Saturday market average of $2558 ± 1025. Similarly, once conditions calmed, the La Reine market again responded with a concerted effort, selling $5100 on Thursday, 2

September 2010. All vendors sold out both days.

3.4.2 Regression Model of Predicted Grounds Selection by Conditions

The binary logistic regression model for predicting if a fisher would opt to fish Lang Bank determined that the following terms were significant: dummy variables for calm wind ($v_w \leq 8.0$ m/s), and the three regulatory conditions: the RHSAA closure (x_r), the MSSAA closure (x_m), and the open conch season (x_c). All coefficients were significant ($p \leq 0.05$). The final model is:

$$f(z) = \frac{1}{1 + e^{-z}} \quad (5)$$

$$z = 2.834 v_w + 0.202 x_r + 0.561 x_m + 1.642 x_c$$

The final, four-term model correctly predicted fishers targeting Lang Bank 61.6% of the time, a 21.1% improvement over the initial, term-less model (40.5% correctly predicted). Table 3-2 presents the model odds ratios (logβ-values) and their p-values, Hosmer-Lemeshow values, and pseudo-r^2 values for the final model. The reported coefficients suggest that the likelihood of choosing to fish at Lang Bank increase when wind speeds are lower and fishers can collect conch. The likelihood decreases significantly during the RHSAA closure, while the MSSAA closure suggests a decreased likelihood during its closed season, despite affecting fishing at the other end of the St. Croix shelf.

Table 3-2 Binary Logistic Model for Predicting Likelihood of Fishing Lang Bank (two-tailed t-test statistic in parentheses at $p \leq 0.05$ unless otherwise noted)

% Predicted (%Improvement)	**Pseudo-r^2 (Hosmer-Lemeshow)**	**Wind Speed $v \leq 8$ m/s**	**RHSAA $x_r = 1$**	**MSSAA $x_m = 1$**	**Conch Season $x_c = 1$**
61.6 (21.1)	0.126 (0.538)	2.834 (0.000)	0.202 (0.000)	0.561 (0.004)	1.642 (0.05)

3.4.3 Economic Model of Expected Landings Value by Grounds

The linear regression model ($r^2 = 0.85$, F = 402.70) took the form:

$$(6)\quad V = 29.12v_w + 144.54v_v + 224.42w_l - 141.50x_r - 18.08x_m + 294.10x_c$$

where the explanatory dummy variables are calm wind speeds ($v_w \leq 8$ m/s), calm sea conditions ($v_v \leq 1.1$ m), selection of Lang Bank (w_l), the RHSAA closure (x_r), MSSAA closure (x_m), and open conch season (x_c). All variables were significant ($p \leq 0.05$). The final linear model predicts a gross daily landed value (± 1.5 standard deviations) per fishing operation to be \$396 ± 165, with a ±1.5σ range of \$150 – \$645. Figures 3-4 through 3-7 present recorded gross value throughout other regulatory periods of 2010.

Lang Bank's coefficient when Lang Bank is targeted ($w_l = 224.42$) indicates that those grounds do possess value as the preferred fishing ground. The two closures indicate that fishers incur losses during those times, with losses during the RHSAA ($x_r = -141.50$) much more acute given their Lang Bank location. Finally, the positive coefficient for the conch season ($x_c = 294.10$) indicates that conch is a highly valued stock for St. Croix. Figure 3-8 compares landings more generally, in terms of the "high season" from 21 January - 30 April, and "low season" (1 May - 3 September). The predicted value of landings per fishing operation is similar to the average recorded values recorded from market observations, \$422 ± 216, although market data show greater variability.

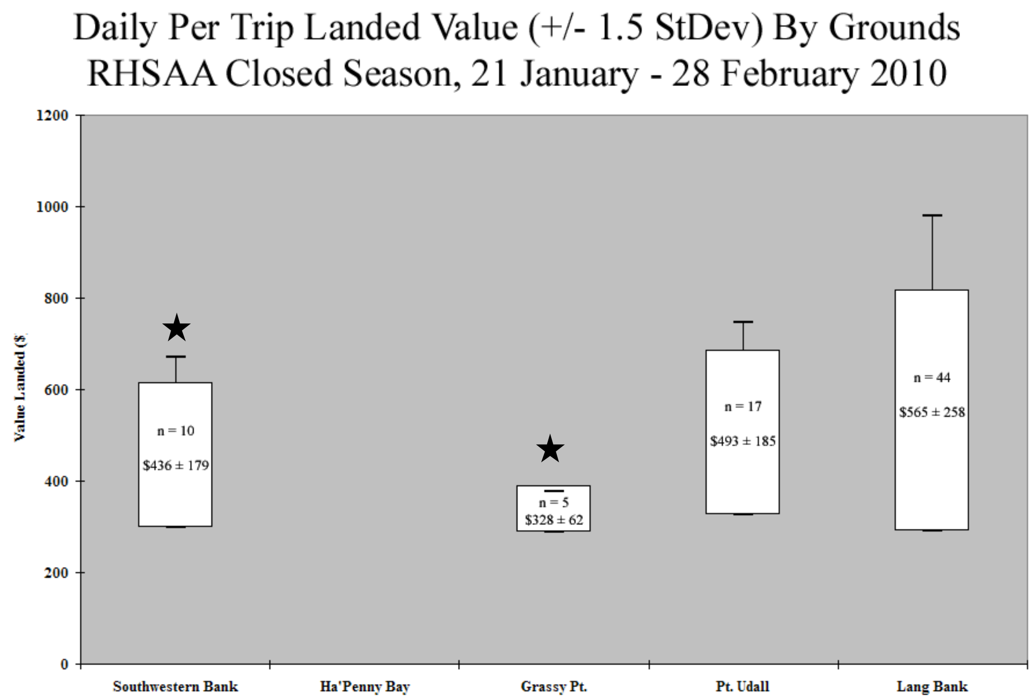


Figure 3-4. Daily per trip landings, by gross value, 21 January - 28 February 2010. (Stars reflect two-tailed t-test comparing daily landings from each grounds to Lang Bank, significant at $p \leq 0.05$; box plot represents +/- 1.5 Standard Deviations from Mean Gross Landed Value, with number of trips (n) and mean included inside box. Tails represent maximum and minimum recorded gross landing for each grounds.)

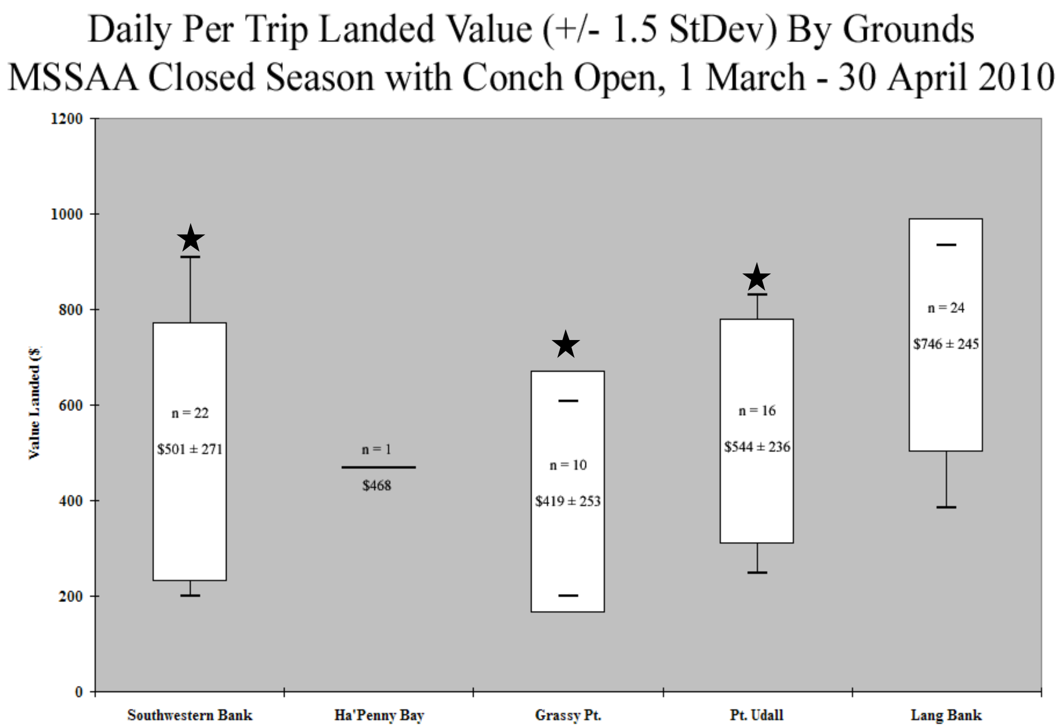


Figure 3-5. Daily per trip landings, by gross value, 1 March - 30 April 2010. (Stars reflect two-tailed t-test comparing daily landings from each grounds to Lang Bank, significant at $p \leq 0.05$; box plot represents ± 1.5 standard deviations from mean gross landed value, with number of trips (n) and mean gross landed value included inside box. Tails represent maximum and minimum recorded gross landing for each grounds.)

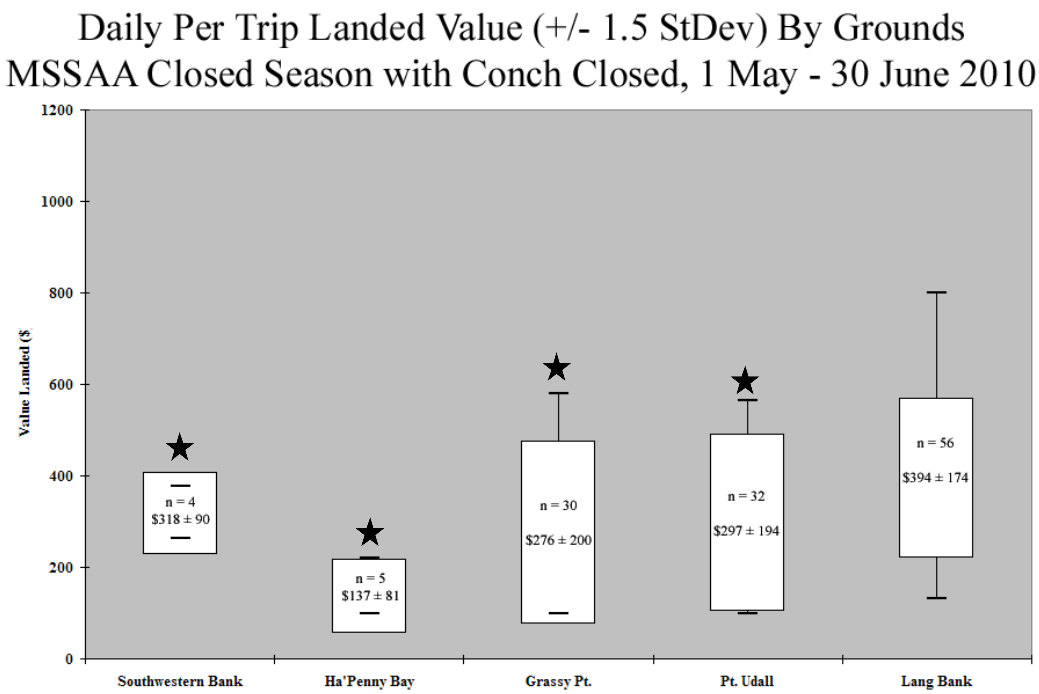


Figure 3-6. Daily per trip landings, by gross value, 1 May - 30 June 2010 (Stars reflect two-tailed t-test comparing daily landings from each grounds to Lang Bank, significant at $p \leq 0.05$; box plot represents ± 1.5 standard deviations from mean gross landed value, with number of trips (n) and mean gross landed value included inside box. Tails represent maximum and minimum recorded gross landing for each grounds.)

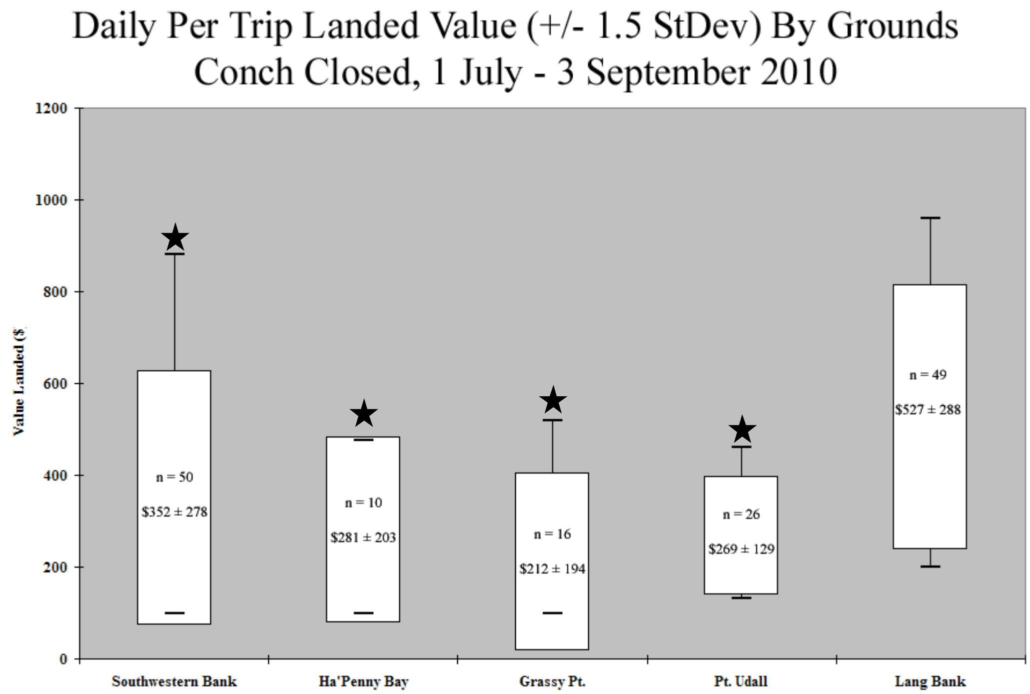
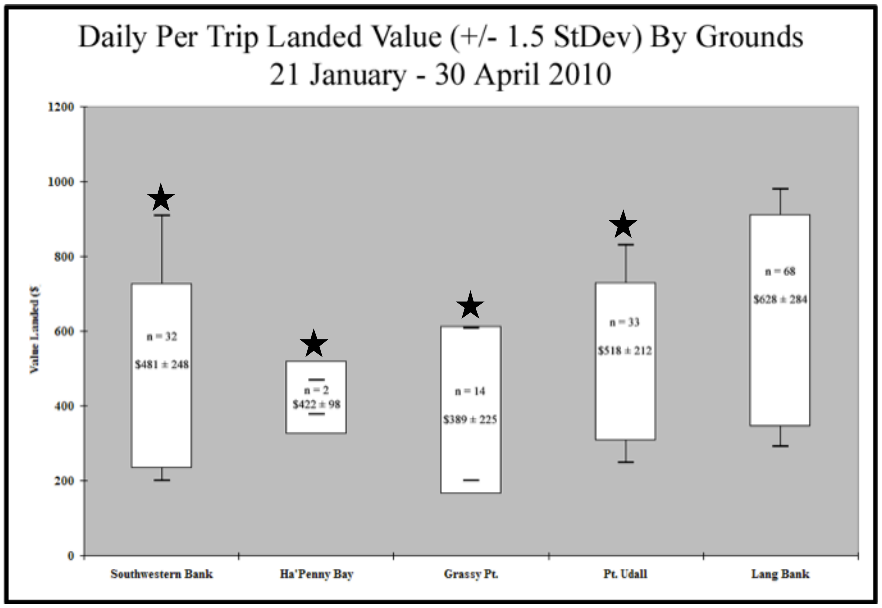


Figure 3-7. Daily per trip landings, by gross value,1 July - 3 September 2010. (Stars reflect two-tailed t-test comparing daily landings from each grounds to Lang Bank, significant at $p \leq 0.05$; box plot represents ± 1.5 standard deviations from mean gross landed value, with number of trips (n) and mean gross landed value included inside box. Tails represent maximum and minimum recorded gross landing for each grounds.)



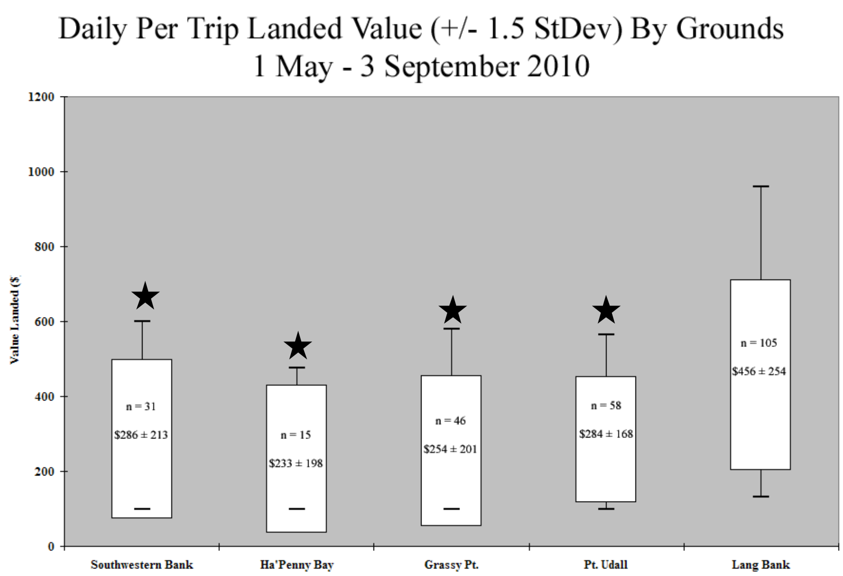


Figure 3-8. Daily per trip landings, by gross value, high vs. low season. (Stars reflect two-tailed t-test comparing daily landings from each grounds to Lang Bank, significant at $p \leq 0.05$; box plot represents ± 1.5 standard deviations from mean gross landed value, with number of trips (n) and mean gross landed value included inside box. Tails represent maximum and minimum recorded gross landing for each grounds.)

3.5 Discussion

3.5.1 Behavioral Models as a Bridge to Improved Management

This study developed and used behavioral and economic models showing that fisher behavior is predictable in St. Croix and to supports the idea that fisheries management is necessarily about managing people (Berkes et al. 2001b; Hilborn 2007b). The coupled model approach has proven capable of estimating how fishers in St. Croix respond to a range of physical and regulatory conditions that affect them economically on a weekly or even daily basis. This ability to focus at the relevant spatial and temporal scale of the fisher is unique to this model's approach, and provides a needed tool that can be used to improve management by reducing uncertainty and recognizing likely fishing and market trends.

Since behavioral and economic models, particularly those designed to be long-term monitoring programs, offers an alternative way forward for managers awaiting regulations. The model built for St. Croix presents fishing and market trends, and can be used to recognize changes in fishing pressure associated with existing regulations, market demands, or other local conditions, and adaptively respond. Recognizing patterns in fishing effort can allow managers to focus limited resources, increasing market sampling and presence when fishing effort is likely to spike upward in response to physical, market, or regulatory conditions. Understanding fishing behavior and opportunistically acting in response to changes in behavior brought on my changing physical or regulatory conditions may be an effective may to parse out limited resources.

We can see in the model that of the three regulatory conditions, the RHSAA is a strong deterrent ($x_r = 0.202$, $p = 0.000$) to the sampled fisher population from going to Lang Bank, despite the fact that of 76 reported trips taken during the RHSAA closed season, 44 were made to Lang Bank. Examining a breakdown of landings data during this period, 36 of these trips returned with conch, totaling 915 lbs. (415 kg), with a market value of $6405, or $178 per trip. All other grounds reported from 21 January through 28 February totaled 552 pounds (250 kg), an average of $156 per trip (n = 24 trips reporting conch). This suggests that fishers view Lang Bank as a productive conch ground, and are specifically going there for conch rather than to take advantage of any direct or peripheral benefit produced by the spawning aggregation of red hind. This is further supported by data from 1 March – 30 April (Figure 3-5), when the largest mean value landed observed during the study period was reported. During this time, Lang Bank produced a mean daily landings per fishing operation of \$746 ± 245 (n = 24 fishing trips), significantly different than all other grounds, despite having statistically similar ground selection frequencies and a strong increase in numbers of trips to and expected value of catch from the southwestern bank just as the MSSAA closure took place (Table 3-1). Although conch and lobster landings also increased, their added value does not fully explain shifts in effort.

Instead, fishers suggested that the shifting of effort by some was due to an awareness of the seasonal up-tick of productivity along the southwestern shelf. Other fishers also insinuated that the mutton snapper no-possession prohibition that begins on 1 April strongly deters fishers from fishing there once the conch season closes (see Figure 3-7, n = 4 reported trips to the southwestern bank from 1 May – 30 June), so they target those grounds in earlier in the year so as not to even give the appearance that they are fishing at or near the MSSAA closure. Both suggested reasons indicate that from a regulatory standpoint, the MSSAA is effective, and that, coupled with the April – June no-possession prohibition, real protections may be having a positive effect on not only mutton snapper populations, but also other targeted stocks (Kojis and Quinn 2011). These findings are further supported by the "rush" to fish the southwestern bank after the MSSAA closure has been lifted by operations who cannot justify the expenses of fishing Lang Bank during the slowest period of the year (Figure 3-7).

Managing at the operant daily or weekly scale of a fisher may be onerous for a more over-arching regulatory framework. The model presented here is both efficient and effective at describing fishing at that scale, and so reduces system uncertainty not by the common approach of initiating more studies, projects, and monitoring programs, but by drawing firm boundaries and then working within those boundaries before repositioning them the next day. This approach mirrors how fishers operate and how most fished reef stocks behave. Conch slowly but surely move up and down the shelf, unburying themselves and rising from deep, unobservable waters and then migrating to suitable grounds for their summer spawning season (Appeldoorn 1994; Stoner and Ray-Culp 2000; Béné and Tewfik 2001). Mutton snapper and red hind follow seasonal, lunar, and behavioral cues that signal when and where to aggregate for spawning (Cummings 2007; Nemeth et al. 2007; Heyman and Kjerfve 2008; Kojis and Quinn 2011). The difference between the scientists' and fishers' understandings of these phenomena is quite clear. Fishers know exactly where, when, and often why these events occur. It is therefore a worthwhile endeavor to understand their behaviors and begin to recognize at least the "when" portion of the uncertainty equation. If such an endeavor were to proceed in a manner suggested by this research, it may be possible that trust is also developed between researcher and fisher, which can open up an opportunity to better unravel the "where" and "why" by engaging in conversations that can lead to a fuller understanding of their motivations, thoughts, and experiences that form their FEK. From such an equitable position where fishers are sought for their opinions and knowledge, the seeds of decentralized, locally relevant management can take root. Once fishers and managers truly develop a working partnership, co-management initiatives can be developed and tested (Berkes 2009).

3.5.2 Limitations of Behavior Models

While the collected data and models do present similar profiles of how effort market landings are related in St. Croix, the strength is demonstrably weaker than other data collection and monitoring technique. Unfortunately for St. Croix, stock censuses and market data collection could improve considerably. Such is the reality of data- and resource-poor SSFs. St. Croix data remains dependent upon volunteered monthly landings reports completed and submitted by fishers. These reports could be used by the model to further improve upon its estimation power, yet researchers were only allowed access to aggregated landings data at the scale of St. Croix, and are only broadly useful as descriptors on seasonal and yearly trends.

More generally, behavior-based models are products of their surroundings. As discussed in the introduction, SSF fishers like those included in this research, rely upon their FEK to make day-to-day decisions. Fishery management is concerned at much larger time scales, and a model is only as useful as long as the conditions that bore it continue to be relevant. In 2010, fishers and managers were still getting used to the conch quota, in its second full year. Additionally, weather conditions, while similar to long-term weather trends for St. Croix, varied relative to the temporal spacing of underlying regulations. As seen, poor weather conditions strongly influence fishing at Lang Bank. But what is the combined effect of a storm arriving say the week before conch season closes and one a week after? Fishers face such scenarios. The model, meanwhile, only predicts general likely behavior under a balance of physical and regulatory conditions that don't currently incorporate economic motivations or an individual's own FEK and familiarity with a particular fishing ground.

Finally, this model is limited by the variables included. Though the percent improvement in the binary logistic model was 21.1%, it is hampered by its reliance on weather conditions as a dominant influence to fisher behavior. Statistical analyses, including sensitivity testing of where bins were established to simplify original data, only partially address the reality of fishing in St. Croix and the sterile process of model development. While post-hoc tests supported the structure of the final behavioral model, they should not be viewed as validation that the model is a suitable substitute to other forms of observation and testing. The models here should continue to be viewed in light of attempting to reduce uncertainty in fishing behavior when there is little other sources of data available and resources remain largely unavailable to build a more comprehensive observation program.

3.5.3 Sources of Error

Though this research has shown that there is potentially tremendous value in developing and utilizing simple models focused on fisher behavior and market trends as a means to address broad levels of uncertainty in fishing effort, stock exploitation, and effectiveness of regulations and protected areas in a data-poor SSF, several caveats are addressed here. Foremost, in any research dependent on building long-term working relationships with individuals, the level of trust and honesty is instrumental in collecting useful data, information, and perspectives. In the case of St. Croix's commercial fishers, this research encountered the full range of issues that frequently appear. Fishers there are tremendously protective of their FEK, sharing their best fishing spots only with trusted friends and family, as they believe that special knowledge confers them with distinct advantages over other fishers. This sense of protection is even stronger when working with researchers and fisheries managers, as St. Croix fishers expect that any shared knowledge only leads to additional regulations that can be used against them. Fishers and fishery managers and scientists maintain a healthy suspicion of one another, and sensitive work that focused not only on their daily income but also was conducted through a research window of fishery health and overexploitation was difficult to simply address, much less overcome.

Researchers were acutely aware at the outset that three difficulties would emerge with regards to data collection and reporting as follows: 1) defining daily targeted grounds accurately; 2) properly identifying and quantifying daily landings; and 3) performing data collection in an unobtrusive manner that didn't overly impact the fishing operation's primary concern of selling their catch. The first issue represents the greatest potential source of error. As a guide, grounds were best defined by a series of corroborating data being collected, namely grounds described by the interviewed fisher, contemporaneous launch site data reports collected by the researchers based on observed departures, arrivals, and boat trailers of fishers. When this was not possible, researchers relied on whichever piece of information they had more confidence in reporting.

More vexing from the point of "defining" a targeted fishing ground, many fishers actually fish across several grounds, particularly during conch season, a practice that the constructed models cannot account for. For example, fishers may opt to conduct two or three dives at Lang Bank and stop in Point Udall's conch grounds on the way home. This routine is highly predictable, suggesting it may be valuable from a behavior-based analysis to combine Lang Bank with Point Udall, while from an ecosystem perspective, the two grounds are dissimilar (NOAA 2008). Fishers stated in interviews that, due to the conch quota and specter of an approaching season, they almost always landed their quota, regardless of that particular day's market demand. As a result, targeted grounds were defined to be the furthest area fished unless there was some indication that a closer ground was more responsible for the composition and contents of the cooler brought to market.

3.6 Conclusion

This study provides examples of coupled behavioral-economic models that may help reduce uncertainty and lead to greater efficiency and management effectiveness in data- and resource-poor SSFs. Understanding and being able to predict fishing behavior at fine temporal and spatial scales can improve management efficiency by deliberately helping to focus limited research, management and enforcement efforts when and where they will have the greatest impact. Within an EBFM framework, understanding and quantifying how fishers' decisions and economically-based behaviors lead to ecological effects felt by the fishery incrementally reduces system uncertainty at the relevant scale of the fisher. In this way, FEK and fishing behavior have an important position within EBFM, and encourages managers to recognize that managing a fishery successfully is dependent in large part to the successful management of the fishers, and ensuring that the fishery-related goods and functions of the ecosystem are not compromised either by unsustainable fishing effort, or poorly-fit regulations that encourage unsustainable behavior. Most importantly, a committed observation presence, focused on FEK, helps build trust between fishers and managers, which, in turn, can support collaboration in developing and implementing locally appropriate management strategies. Fisher behavior is the key.

CHAPTER IV
A BASELINE ASSESSMENT OF A SPAWNING AGGREGATION POPULATION OF MUTTON SNAPPER (*LUTJANUS ANALIS*) FOLLOWING REGULATORY PROTECTIONS

4.1 Introduction

The mutton snapper (*Lutjanis analis,* Cuvier 1828) is an important food fish for the U.S. Caribbean, highly sought by commercial and recreational fishers and prized for its high quality flesh and low propensity for being ciguatoxic (Coles 2001). In the U.S. Virgin Islands (USVI), *L. analis* is often called "Virgin snapper", a reflection of its popularity and contribution to the island's fishing history and culture. As a member of the Snapper Unit 3 (CFMC 2009a), *L. analis* is a managed species in U.S. Caribbean waters, with complementary territorial regulations in both Puerto Rico (DNER 2004) and the USVI (DPNR 2009). Of particular interest to this research is a jointly-managed seasonal area closure, the Mutton Snapper Spawning Aggregation Area (MSSAA), established along the southwestern shelf edge of the island of St. Croix.

The MSSAA exist from 1 March – 30 June each year (DPNR 2009), protecting a described spawning aggregation area during the peak *L. analis* spawning season (CFMC 1993). The MSSAA was established by federal regulations (58 FR 53145) in 1993. Protections were expanded to include a no-fishing / no-possession regulation in all federal waters in 2005 from 1 April – 30 June (50 CFR 622), a regulation that was extended into territorial waters in 2006 (9 VIC 316), with the intent of improving regulatory compliance and facilitate effective enforcement.

The southwestern shelf of St. Croix, including the area encompassed by the MSSAA can be described as a mixed reef system, with spur-and-groove coral reefs along the fore reef, leading to shallower back reef areas consisting of algal flats, gorgonian plains, seagrass, and sand-algal flats (NOAA 2008; Kojis and Quinn 2011). The dramatic shelf edge drops from 25 m to 200 m in approximately 0.75 km. The shelf shares geomorphologial features of other known snapper spawning aggregation sites

(Heyman and Kjerfve 2008; Kobara and Heyman 2010). *L. analis* populations in the eastern Caribbean are thought to aggregate and spawn in deeper waters (40 – 60 m) from late March through May and perhaps into the summer months (CFMC 1993; Watanabe 2001; Cummings 2007), with peak activity in the days following the full moons from April through June (CFMC 1993; Heyman and Kjerfve 2008).

Fish stock data assessments are incomplete for many species in St. Croix (CFMC 2004), and as a result, data from the much different fisheries of Puerto Rico have been substituted in the development of regulations for all of the US Caribbean, drawing criticism and complaints by fishers who recognized the inapplicability of the data (Joy 2005; Freehill 2007b; Lett 2007). While fisheries managers cannot address every issue facing fish communities, they should utilize resources to conduct stock assessments that can be used to better describe the current status of fished stocks. In cases of managed fishes like *L. analis*, managers should review and quantify the effects of existing regulations on the anticipated benefits of protections that would allow stocks to recover.

This study evaluates the composition and status of the last known spawning aggregation of *L. analis* following 16 years of its seasonal area closure, and three years of seasonal full protection (no possession) of the species throughout St. Croix. This is the first study undertaken since the establishment of the MSSAA in 1993 (CFMC 1993) to specifically describe the population structure of *L. analis*, using traditional fishery metrics of length, weight, fecundity, and catch-per-unit-effort (CPUE), as well as by age-class composition. A long-lived snapper, with estimates suggesting they can reach ages of 25 years or more (Burton 2002), assessing the current status of *L. analis* and any extant spawning aggregation in St. Croix will provide much needed information to fisheries managers. Additionally, by comparing the population metrics data obtained in this study to similar data from other areas, this study can be used an indicator of health of the spawning population and evaluate the effectiveness of the management of this species to date. Finally, this study provides a baseline from which researchers and managers can accurately monitor the composition of the aggregation over time.

4.2 Methodology

Sampling of *L. analis* was conducted over full moon periods from April – June 2009 at a site inside the MSSAA described by local fishers to be the center of the aggregation. Researchers and accompanying commercial fishers began fishing for *L. analis* at dusk. Monthly research quotas allowed for 30 *L. analis* to be caught and kept, leading to a maximum of 90 fish caught. Additional *L. analis* were purchased outside of the closed season (March and July 2009, March 2010) at several fish markets around St. Croix to increase the total sample.

Fish were caught using 200-lbs. test monofilament handlines, baited with ballyhoo (*Hemiramphus brasiliensis*) and sea robin (*Decapterus sp.*) on size 8 J-hooks. Lines were fed out with predominant currents and allowed to sink to within 1 – 2 m of the bottom. Chumming and fluorescent lights were used as fish attractants. Caught fish were quickly brought to the surface to prevent accidental loss via either slipping the hook or shark predation.

4.2.1 Biometric Analyses

Each fish was weighed with a 20-kg digital scale to the nearest gram and weights were reported in grams. Fork length (FL) was measured via measuring board to the nearest millimeter and lengths were reported in millimeters. Sexed gonads were weighed to the nearest hundredth of a gram, their condition described in terms of gonadal maturation. For immature gonads, microscopic analysis was completed to identify characteristic oogonia of female ovaries. Fish purchased in March 2009 were frozen prior to their analysis. Freezing effects, such as shortening of length (Armstrong and Stewart 1997), were reported and corrected by comparing four sample fish fork length measurements before and after freezing before inclusion into the dataset. For all other captured or purchased fish, whole fish were kept on ice prior to processing, which occurred within 24 hours. All tissue samples were preserved in 70% isopropyl alcohol for future analyses. For each fish, length-weight ratios were calculated. Nightly male:female sex ratios were calculated for caught fish.

4.2.2 Gonadosomatic Index Analysis

Following sexing, gonadosomatic index (GSI) values were calculated for both male and female *L. analis*:

(1) GSI = gonad weight (g) *100 / fish weight (g)

For females, fecundity values were also calculated by extracting two subsamples from mature female gonads, one from each of the paired ovaries. Subsamples were weighed to the nearest hundredth of gram and fixed in 70% isopropyl alcohol. Fecundity was then calculated:

(2) Fecundity = $(GW_x / SW_{xy}) \bullet N_{xy}$

Where: GW_x = Total weight (g) of gonad sample x

SW_{xy} = Subsample y weight (g) of gonad sample x

N_{xy} = Number eggs counted in subsample y of gonad x

Egg diameter (both oogonia and oocytes) from at least one subsample per gonad was measured via ocular mirometer, with a minimum of 100 eggs counted per subsample. Oocytes with a diameter approximately greater than 0.53 mm were classed as Vtg3 oocyets (tertiary vitellogenic oocytes) and early stages of oocyte maturation and germinal vesicle migration (Brown-Peterson et al. 2009). Fecundity was estimated (Equation 2). For each sampled female gonad pair, a coefficient of variation was calculated to estimate the variation in egg counts between subsamples.

4.2.3 Sagittal Otolith Sampling

Sagittal otolith pairs were removed during fish dissection by accessing the otolith casings posteriorly with a hand chisel and tweezers. Otoliths were then labeled, cleaned, dried, and stored in individually labeled envelopes prior to analysis. Where both otoliths were not damaged, the left otolith was used for age analysis. Otoliths were embedded in two-part Epoheat epoxy (Buehler) and cured for at 55ºC for at least 24 hours. The first section cut used a low-speed Isomet saw with 0.5” wafering blade, following methods described by Potts and Manooch (1995). The cut block was then mounted onto a glass slide with Epoheat, cut side down. The mounted block was then again cut to <250 µm using the same Isomet saw and then sectioned to a width of <125 µm with a Hillquist thin-section machine with diamond-surfaced low-speed grinder. Following sectioning, samples were hand polished over three intervals with 320-grit silicon carbide, 600-grit alumina, and 9.5-µm alumina and then buffed over two intervals using Buehler 8-in. polishing wheel at 3-µm and 0.3-µm alumina-polish microcloth.

Each thin-section slide was scanned using a modified Nikon Coolscan 8000 transparency scanner at 4000 dpi with and without cross-polarizing filters. Each scan was saved as an uncompressed .tif file and analyzed with Adobe Photoshop (v7.0). Otolith annuli counts were completed following protocol to determine the age of each individual fish (Potts and Manooch 1995; Campana 2001; Burton 2002).

4.2.4 Data Presentation and Analyses

The completed dataset was constructed to correlate length, weight, age, sex, and gonad condition, for each *L. analis* sampled. Length-weight and length-age relationships were graphed using statistical software (SPSS v17.0). For each graphical presentation, best-fit lines and accompanying equations and statistics were calculated and presented.

4.3 Results

4.3.1 Biometric Analyses

Over the course of the collection period, 128 *L. analis* were sampled, 95 caught between April – June 2009 within the MSSAA, while 13 were purchased in March and June 2009 and 20 purchased in March 2010. Table 4-1 presents summary catch statistics. Nightly catches were sluggish in April, but peaked on 11 May 2009, three days after the full moon, with 34 *L. analis* captured (mean FL = 492 ± 73 mm). The next night an additional 25 snappers were caught (mean FL = 488 ± 69 mm). Neither the difference in fork lengths nor sex ratios between the two nights were significant. Collection resumed in June, with 16 *L. analis* (mean FL = 560 ± 68 mm) caught on 9 June (+2 day after full moon), and 13 (mean FL = 439 ± 64 mm) captured on 11 June. Mean lengths were significantly different between the two nights (two-tailed t-test, $p \leq 0.01$). Fishing concluded on 12 June, capturing two *L. analis* (mean FL = 643 ± 25 mm).

Table 4-1 Summary Catch Statistics for *L. analis* in MSSAA, April – June 2009

Date (+/- d Full Moon)	**Count**	**Sex Ratio (M : F)**	**Mean FL (mm)**	**SD (mm)**	**FL Range (mm)**
6 April (-3 d)	1	1 : 0	620	--	620
7 April (-2 d)	4	0.33 : 1	584	65	490-635
11 May (+3 d)	34	2.4 : 1	492	73	367-628
12 May (+4 d)	25	4.2 : 1	488	69	380-633
9 June (+2 d)	16	4 : 1	560	68	455-650
11 June (+4 d)	13	2.6 : 1	439	64	375-616
12 June (+5 d)	2	1 : 1	643	25	625-660
TOTAL	95	3.3 : 1	503	81	367-660

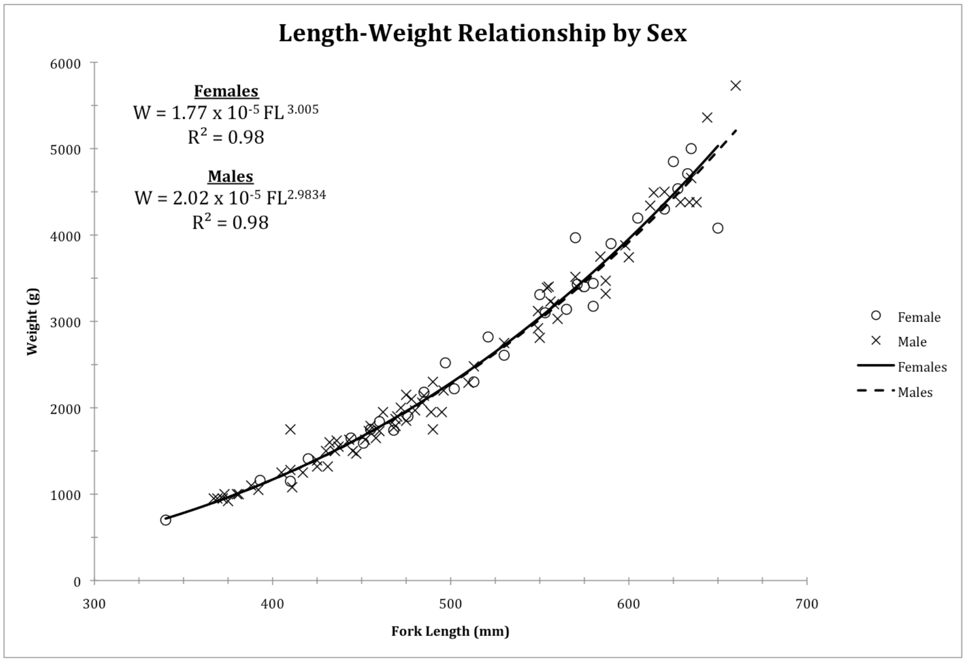


Figure 4-1. Length-weight curve for *L. analis*, by sex, from St. Croix, 2009-2010.

The mean weight of all mutton snapper caught in the MSSAA was 2.47 ± 1.19 kg (n = 94 fish). One captured male fish was bitten in half prior to being landed and was excluded from the weight sample. The mean weight of females (3.09 ± 1.16 kg, n = 29) was significantly larger (2-tailed t-test, $p \leq 0.001$) than the mean weight of males (2.22 ± 1.11 kg, n = 65). A length-weight curve was estimated by a best-fit plot for both *L. analis* sexes (Figure 4-1).

4.3.2 Fecundity Analysis

GSI values were highest for April – June 2009 for both sexes of *L. analis* (Tables 4-2 and 4-3). The maximum GSI for female fish was 5.61, captured on 9 June 2009, while for males the maximum was 5.49, caught on 12 May 2009. GSI was lower and more variable for July 2009, and included one female with visibly spent gonads. This female was sampled on 18 July 2009, 11 days after full moon.

Table 4-2 Gonadosomatic Indices for Female *L. analis*, by Capture Period

	Mar 2009	Apr 2009	May 2009	Jun 2009	Jul 2009	Mar 2010
N	2	3	16	10	4	5
GSI	0.28	2.94	3.04	3.12	1.82	0.47
S.E.	0.14	0.46	0.22	0.37	0.75	0.13
Mean FL (mm)	493	615	539	525	602	453
FL Range	386-599	590-635	410-633	393-625	550-633	340-513

Table 4-3 Gonadosomatic Indices for Male *L. analis*, by Capture Period

	Mar 2009	Apr 2009	May 2009	Jun 2009	Jul 2009	Mar 2010
N	4	2	43	20	3	14
GSI	0.12	2.14	2.86	2.98	0.93	1.38
S.E.	0.05	1.86	0.21	0.30	0.24	0.23
Mean FL (mm)	427	555	472	503	628	497
FL Range	369-475	490-620	367-600	375-660	605-644	373-598

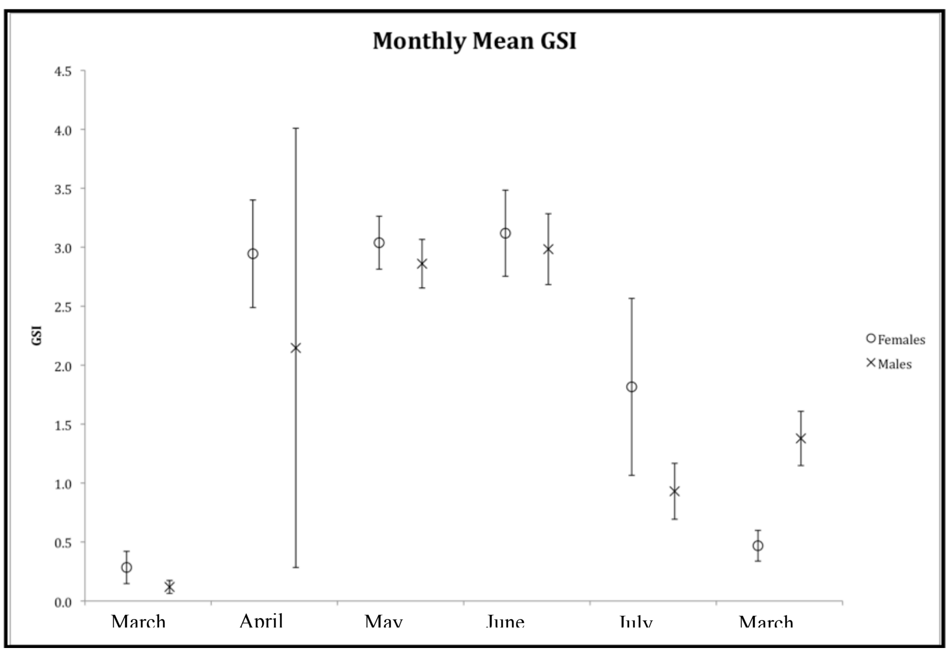


Figure 4-2. Monthly mean (± S.E.) gonadosomatic index for *L. analis*, by sex.

GSI was lowest for March 2009 and 2010, reflecting the higher proportion of small-sized males (Figure 4-2). The larger of two females sampled in March 2009 also had a low GSI of 0.42, despite a fork length of 599 mm. The observed difference in GSI between years for males is likely an artifact of the proportionally larger March 2010 sample size and timing of lunar periodicity. The first spring full moon in 2009 occurred on 9 April, while in 2010 it fell on 30 March. As the spring full moon is an important environmental cue for *L. analis* spawning aggregation formation, with aggregations taking shape several days prior to the full moon, the March 2010 GSI values, particularly for males, reflect this increased activity.

4.3.3 Otolith Analysis

Of the 128 *L. analis* sampled, 106 (83%) were able to be included in the ageing analysis. Seventeen otoliths were unreadable following thin-sectioning, one set was lost, and four sets were damaged or chipped during their collection and transport. Tables 4-4 and 4-5 provides descriptive statistics, by sex, for the 106 *L. analis.*

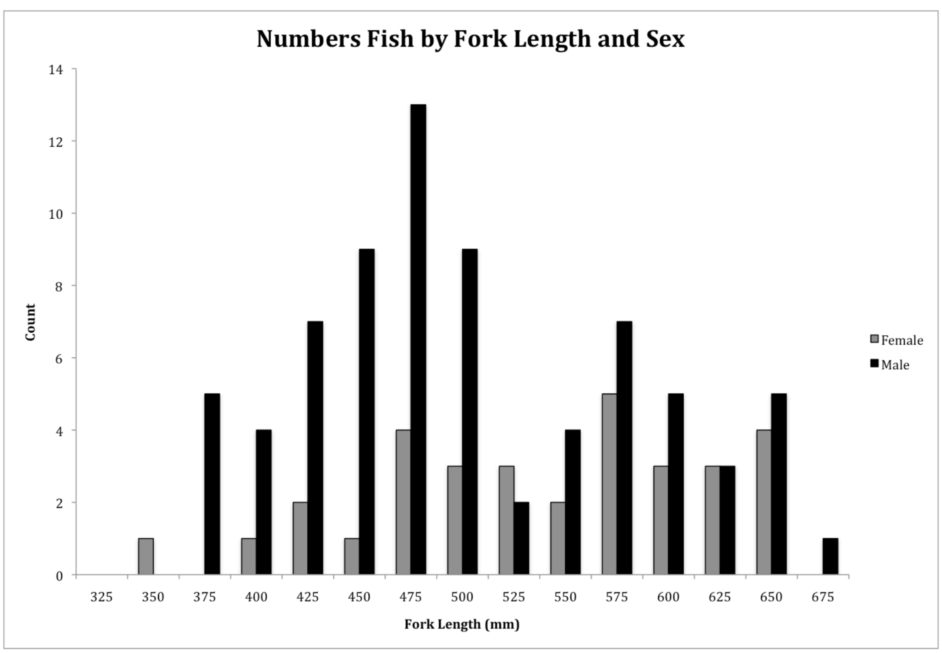


Figure 4-3. Numbers of *L. analis* sampled, by fork length and sex

Table 4-4 Descriptive Statistics of Sampled Population – Female *L. analis*

Age (yrs)	Count	Mean FL (mm)	SD (mm)	FL Range (mm)
1	1	340	--	340
2	3	424	39.3	393-463
3	2	456	6.4	451-468
4	6	466	32.8	420-513
5	3	518	14.4	502-530
6	6	559	32.1	497-580
7	4	585	32.9	550-620
8	5	614	32.7	570-650
9	2	631	5.3	627-635

Table 4-5 Descriptive Statistics of Sampled Population – Male *L. analis*

Age (yrs)	Count	Mean FL (mm)	SD (mm)	FL Range (mm)
1	1	367	--	367
2	16	406	31.2	369-468
3	18	452	29.3	405-510
4	8	470	20.5	435-490
5	7	503	29.2	472-549
6	8	553	29.7	485-587
7	7	590	26.4	549-628
8	5	609	34.0	555-638
9	4	638	19.2	614-660

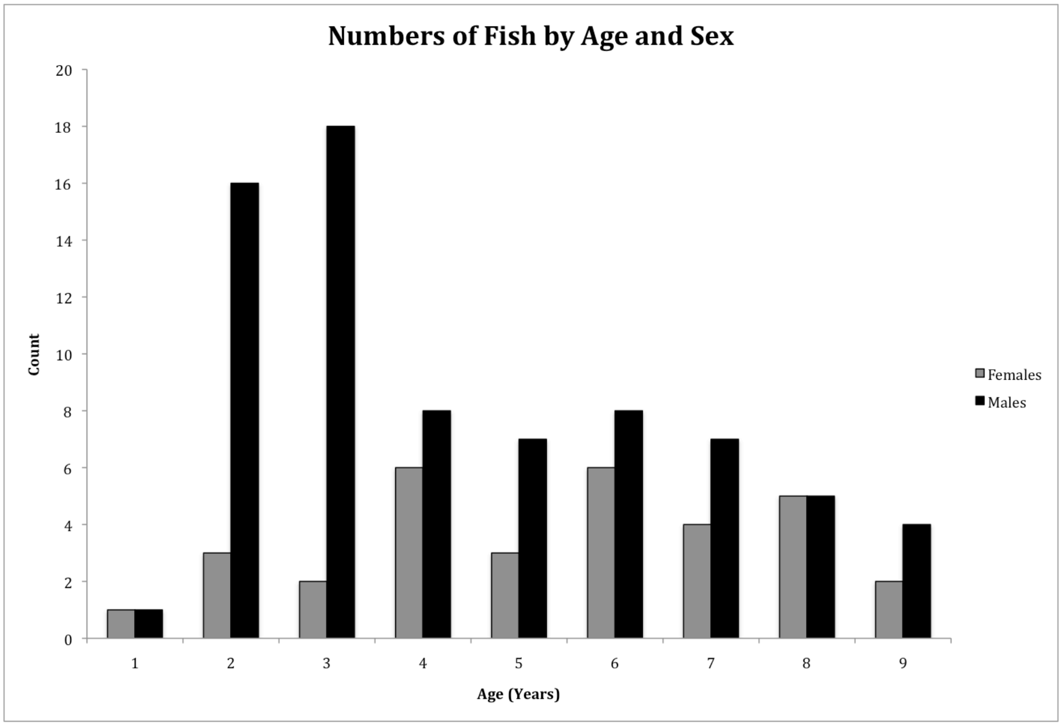


Figure 4-4. Numbers of *L. analis* sampled, by age class and sex.

The otolith analysis identified age classes from Year 1 to Year 9 for both males and females. The mean age of males was 4.4 ± 2.2 yrs (S.E. = 0.26). The mean age of females was 5.4 ± 2.2 yrs (S.E. = 0.39). The difference in mean ages between the two groups was significant (two-tailed t-test, $p = 0.03$). Figure 4-3 presents the sampled population distribution, by fork length and sex, while Figure 4-4 presents the distribution by age and sex.

The largest age class for males (n = 74 individuals) was Year 3 ($n_3 = 18$ individuals), averaging 452 ± 29.3 mm FL, and ranging from 405 – 510 mm FL. For females (n = 32 individuals), the largest age classes were Years 4 and 6, both with six individuals. For Year 4, the mean fork length 466 ± 32.8 mm FL, while Year 6 averaged 559 ± 32.1 mm FL. Size classes between sexes were not statistically significant. Male *L. analis* were predominant, with 58% of captured males falling in Year 1 – 4 classes (n = 43 individuals). The maximum size for male *L. analis* was a 660 mm, 5.73 kg, Year 9

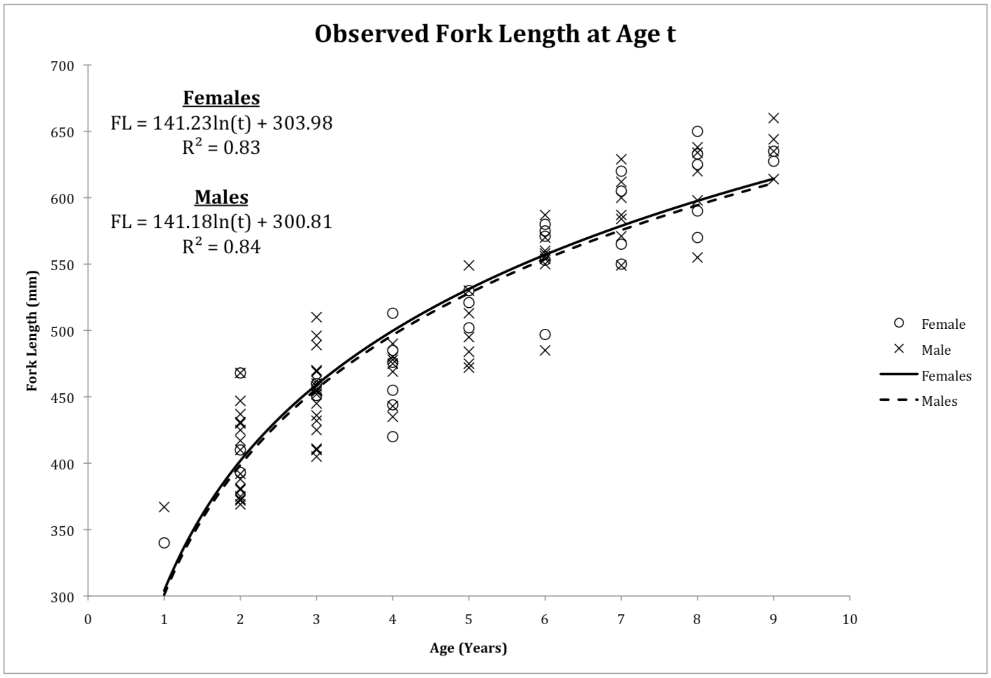


Figure 4-5. Length - age curve for *L. analis*, by sex, for St. Croix, 2009-2010.

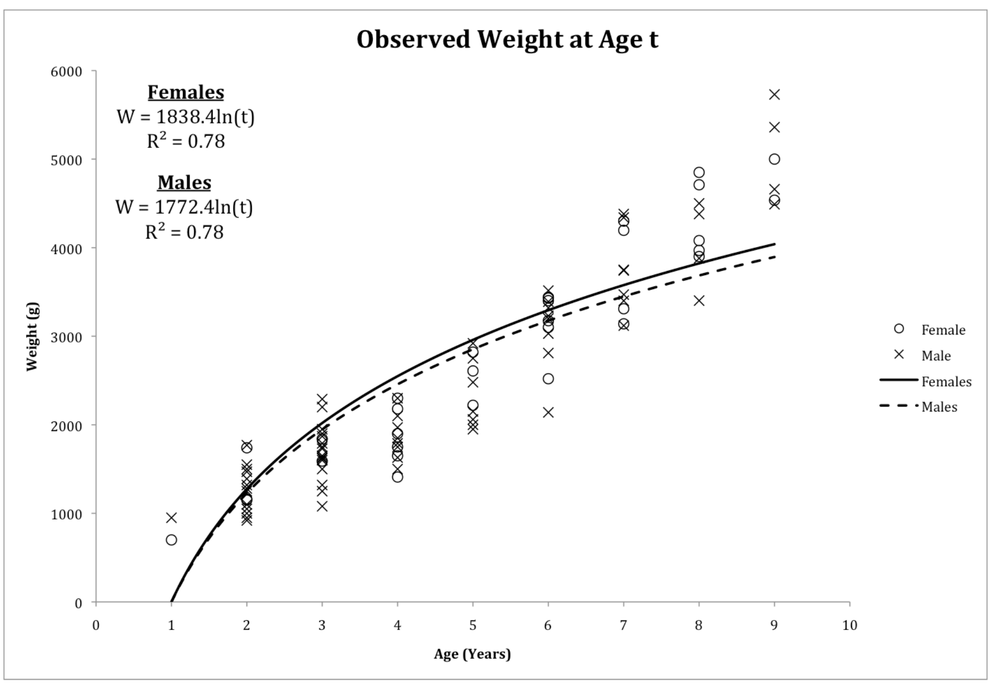


Figure 4-6. Weight - age curve for *L. analis*, by sex, for St. Croix, 2009-2010.

fish. The maximum size for female *L. analis* was 650 mm, while a second female weighed 5.0 kg. Both individuals were members of the Year 9 cohort. Figure 4-5 presents the estimated length-at-age curve for both males and females, while Figure 4-6 presents the estimated weight-at-age curves.

Age at first maturity was calculated via logistic regression of fork length and estimates of gonadal maturity. The 95% confidence interval for size at first maturity is 330 – 410 mm FL (Figure 4-7), based on Ungaro (2008) standard that "size at which 50% of the population attains an advanced stage of gonad development (L_{m50})."

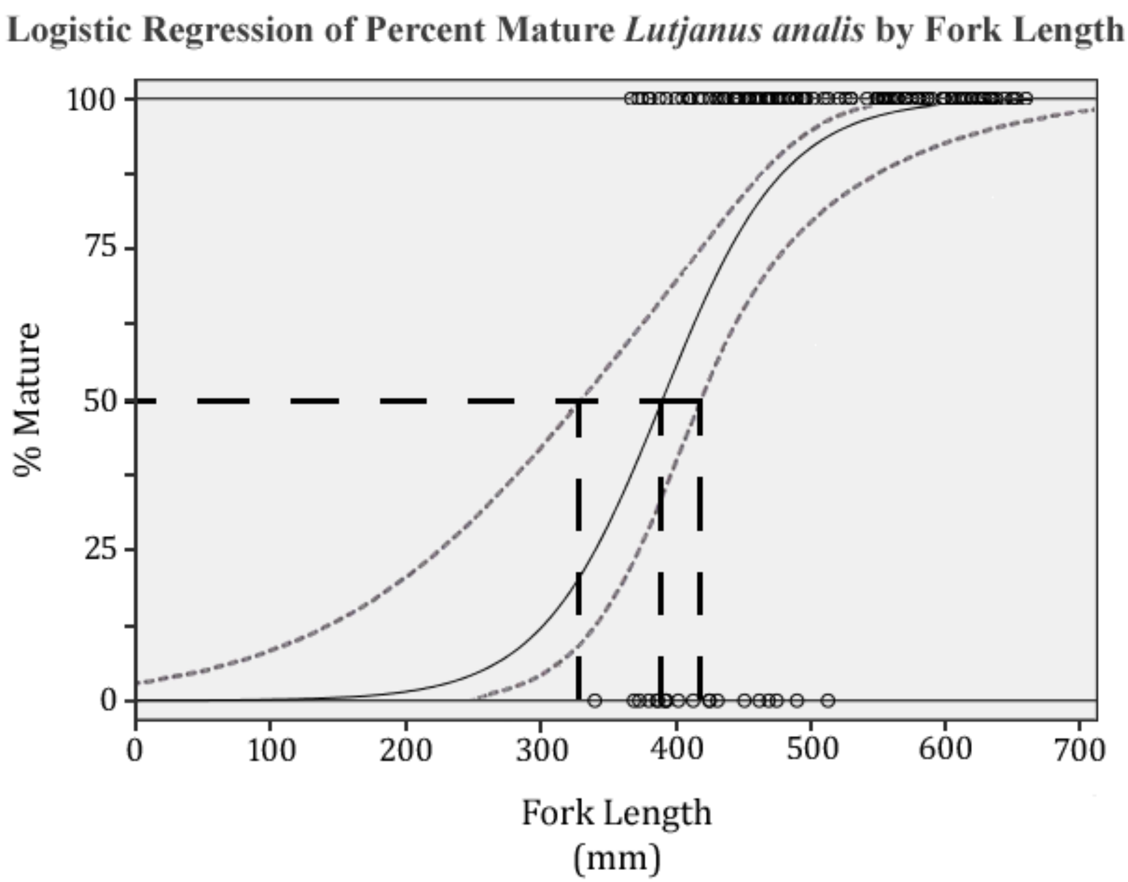


Figure 4-7. Logistic regression of percent mature *L. analis* by fork length.

Table 4-6 Spawning Documentation for Caribbean Region, by Month

Location	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Cuba [1]		○	○	●	●	○	○	
Cuba [2]			○	●	●	○	○	○
Puerto Rico [3]			○	○	○			
Puerto Rico [4]		●	●	●	○			
La Parguera, PR [5]			●					
Belize [6]	○	●	●	●	●	○		○
Gladden Spit, Belize [7]		○	●	●	○	○		
Gladden Spit, Belize [8]		○	●	●	●			
U.S. Caribbean [9]		●	●	●	○			
Florida [10]		○	○	●	●	○		
N.E. Caribbean [11]	○	●	●	●	○	○		
St. Croix, USVI [12]			○	●	●	○		

○ Denotes Spawning Period
● Denotes Peak Spawning Period

1. Claro et al. (2001; 2009)
2. Claro and Lindeman (2003) - summary; spawning months varied among sites
3. Matos-Caraballo et al. (2006)
4. Ojeda-Serrano et al. (2007) - based on fisher interviews
5. Esteves-Amador (2005) - based on catch monitoring for *L. analis* in April 2003
6. Heyman and Kjerfve (2008) - based on direct visual observations by divers as well as fishery-dependent observations and fisher-provided information
7. Heyman et al. (2004)
8. Graham et al. (2008)
9. CFMC (2005)
10. Burton (2002) , Burton et al. (2005)
11. Erdman (1977)
12. This study

Table 4-7 Documented Spawning Activity for *L. analis* in Relation to Full Moon

	-3	-2	-1	FM	+1	+2	+3	+4	+5	+6	+7	+8	+9
La Parguera [1]			○	-	-	-	-	○	○	●	○	○	
Gladden Spit [2]								○	○	○	○	○	○
Gladden Spit [3]		○	○	○	○	○	○	○	○	○	○		
Cuba [4]	○	○	○	○	○	○	○	○	○	○	○		
St. Croix, USVI [5,6]	○	○	-	-	●	●	●	●	-	-	-	-	-

○ Denotes Spawning Period
● Denotes Peak Spawning Period
- Denotes "No Fishing"
FM Denotes Full Moon

1. Esteves-Amador (2005)
2. Heyman et al. (2004). Spawning activity was reported at Gladden Spit up to 13 days after the full moon.
3. Heyman and Kjerfve (2008)
4. Claro and Lindeman (2003)
5. This study, based on catches in the MSSAA. Fishing terminated each month by four days after the full moon due to reaching the monthly research catch limit permit of 30 *L. analis*.
6. April 2009 was the only month *L. analis* was fished for prior to the full moon (8 April 2009). Three days before the full moon, one *L. analis* was caught, a mature female, and 11 *Ocyurus chrysurus (*yellowtail snapper). Two days before the April 2009 full moon, four *L. analis* (one male and three mature females) and nine *O. chrysurus* were caught. Four days after the April 2009 full moon, no *L. analis* and nine *O. chrysurus* were caught.

4.4 Discussion

4.4.1 Status of Mutton Snapper Spawning Aggregation

Based on GSI data collected in this study, spawning aggregations for *L. analis* in St. Croix appear to peak in May and June (Tables 4-2, 4-3; Figure 4-2), similar to several other locations elsewhere in the Caribbean (Table 4-6). Likely peak spawning activity occurs two to four days after the full moon (Table 4-7). These observations follow initial reports for the MSSAA aggregation (CFMC 1993), as well as reports from elsewhere throughout the Caribbean (Claro and Lindeman 2003; Matos-Caraballo, Cartagena-Haddock, and Pena-Alvarado 2006; Graham et al. 2008; Heyman and Kjerfve 2008). Spawning may continue past four days after the full moon, but monthly sampling was halted once 30 *L. analis* were captured. With the exception of April 2009, this catch limit was reached within four days of the full moon. Overall, CPUE ranged from 10.1 - 14.4 kg per fisher per hour spent fishing. Incorporating measured GSI and catch-per-unit-effort (CPUE) estimates, it appears that the May and June *L. analis* spawning aggregations remain extant.

4.5 Conclusions

Recognizing that the sample dataset is small and that interpretation of results is therefore limited, the *L. analis* spawning aggregation continues to at least form, making it an extant aggregation of unknown size and total reproductive capacity. Examining data collected, the *L. analis* spawning aggregation in St. Croix appears to be healthy based on CPUE estimates and balanced sex ratios, particularly of old, larger fishes, where fecundity is greater. The range of GSI values reported (Figure 4-3) are higher than a similarly-sized study of *L. analis* in northeastern Brazil (Teixeira, Duarte, and Perreira 2010), and 90 of 128 GSI values calculated were greater than 1.5, one metric for identifying mature *L. analis* individuals (Froese and Pauly 2000).

The results of this study point to the potential that existing protections for *L. analis* during their spawning season may be providing some level of stock protection and recovery. Despite fishery-dependent evidence presented here that *L. analis* are aggregating to spawn in the area of the MSSAA from April through June each year, direct observation of the aggregation forming, or the behavior of the aggregation's individuals, including courtship and spawning, has not yet been made. These preliminary results should encourage further interest in searching for and describing the extant aggregation, its estimated size and potential reproductive effort, its location, and how it changes in response to seasonal and daily variability in physical conditions. The tools and techniques exist to rapidly characterize the shelf geomorphology (Heyman, Ecochard, and Biasi 2007), and can be utilized to also find large densities of fish via sonar (i.e. fish finders). This research should not limit itself to the MSSAA, but expand its scope to include the whole of St. Croix's southwestern shelf, particularly the shelf elbow to the west of the MSSAA. Given the daily behaviors of *L. analis*, it is unlikely that an aggregation will be encountered without identifying transit routes from deeper aggregation areas to shallower feeding grounds, diving those areas at crepuscular hours, and performing fishery-dependent studies in the early night hours when *L. analis* are likely most actively feeding.

This study was completed with the full involvement of several commercial fishers. Indeed, their cooperation was instrumental in locating successful fishing sites and completing the sampling effort. Looking forward, strengthening the fisher-scientist partnership with similar opportunities provides much-needed cooperation for an island and fishery that retains high levels of mutual mistrust between the groups. Given limited management and enforcement resources, maintaining the benefits and allowing the recovery of the local *L. analis* population to continue will require fishers voluntarily complying with regulations. Their support and participation in research and monitoring will remain a valuable asset for managing fisheries sustainably in St. Croix.

CHAPTER V
CONCLUSION: TESTING PUBLIC SUPPORT FOR FISHER-DEVELOPED ALTERNATIVES TO REGULATORY FRAMEWORKS: THE DISCRETE CHOICE METHOD APPROACH FOR EXAMINING FISHERY MANAGEMENT

5.1 Introduction

5.1.1 Value of Fishers' Ecological Knowledge in Ecosystem-Based Fisheries Management

Fisheries management is moving from traditional regulatory approaches that focus on single species and on reducing fishing effort incrementally (Wilen 1985) to holistic, ecosystem-based fisheries management (EBFM) approaches (Pikitch et al. 2004). Support for this approach change comes from the recognition that fishery uncertainty cannot be fully reduced or overcome (Schrank 2007), but that productive, well managed functional ecosystems produce sustainable streams of goods and services (Brodziak and Link 2002; Murawski 2007). Furthering this shift at local levels and particularly with small-scale fisheries (SSFs), the benefits of incorporating fishers' ecological knowledge (FEK) has shown promise and a possible way forward for developing and improving management at relevant scales (Johannes, Freeman, and Hamilton 2000; O'Donnell, Pajaro, and Vincent 2010).

FEK can be utilized within a management setting as a qualitative substitute for describing a fishery's functionality and trends over time (Wilson, Raakjær, and Degnbol 2006; Silvano and Valbo-Jørgensen 2008). Despite a lack of scientific rigor, FEK possesses value at local scales, and may be the only form of knowledge for many 'data-poor' fisheries (Johannes 1998; Pikitch et al. 2004; Drew 2005). It is built upon fishers' work in a fishery, their observations of stock behaviors and changes, and the social and economic demands placed on fishers in their daily quest to be profitable in the fishery (Béné and Tewfik 2001). FEK can help research and monitoring efforts by identifying essential fish habitat, trends in stock abundance and seasonal movements, and general descriptions on habitat and marine community health (Berkes, Colding, and Folke 2000; Johannes 2002; Silvano and Valbo-Jørgensen 2008). If diligently followed, FEK and fisher behavior can present a near real-time assessment of the fishery that traditional monitoring or research programs cannot remotely mimic.

The ability of FEK to identify and describe essential fish habitat (EFH), in particular, has shown great promise within EBFM frameworks (St. Martin 2001; Bergmann et al. 2004). EFH is defined by provisions within the Magnuson-Stevens Act (50 CFR §600) to be "those waters and substrate necessary to fish for spawning, breeding, feeding, and/or growth to maturity." Levin and Stunz (2005, 71) offer a critique of the utility of this definition as "the ability of fisheries managers to identify EFH depends on knowledge of what habitats fish use… However, since all habitats used by all life history stages are included in EFH descriptions, [EFH] is defined very broadly." FEK can be used as a substitute in instances where managers cannot describe or prioritize among areas identified as EFH. This ability is perhaps most valuable for situating no-take marine protected areas (MPAs) in locations to maximize ecosystem benefits.

Properly designed and EBFM-based MPAs offer protections for a full suite of ecological services and functions in a manner that other tools cannot, making the health of the ecosystem the primary management concern (Pikitch et al. 2004; Smith et al. 2007). Even in instances where data is limited, establishing an MPA at purported critical habitats may provide some level of protection above having none (Johannes 1998). Indeed, MPAs have become over the past decade a preferred management strategy for large-scale (Fernandes et al. 2005) and local scale (Roberts, Bohnsack, et al. 2001; Nemeth 2005) fisheries and as a valuable tool that can support EBFM. MPAs can effectively reduce the need for data-reliant decision-making by accepting that fishery dynamics, while not fully described or understood, are likely maintained at some functional level inside the reserve.

That being said, reducing system uncertainty remains a chief concern of EBFM (Crowder et al. 2000; Halpern et al. 2006), particularly with determining where MPAs would provide the greatest benefits both to the ecosystem and the surrounding fisheries. EBFM, by establishing an MPA, relies on maintaining critical habitats and vulnerable life stages. Overlooking or ignoring any particular element can result in the reduction or forfeiture of anticipated benefits (Cook and Heinen 2005). When a fishery is hampered by a lack of quantitative data or scientific monitoring, the ability to successfully locate and then protect EFH is reduced. This fact requires EBFM frameworks to remain precautionary against the effects of uncertain system dynamics (Lauck et al. 1998), a view that has been pragmatically refined to examine risk in management options (Hilborn 2007a; Fenichel et al. 2008; Sethi 2010).

One way that EBFM guards against uncertainty is to implement large networks of MPAs that protect not only ecosystem functionality, but also important connectivity linkages between habitats and systems that are necessary at different junctures of any stock's life history. This precautionary approach to MPA number and size encourages protecting 20 - 30% of all fishable grounds as no-take MPAs (Bohnsack et al. 2000; Balmford et al. 2004), a laudable goal from the perspective of conservative management, but one that is not likely to be politically feasible for most parts of the world (Roberts, Halpern, et al. 2001; Agardy 2003).

The political reality is that no-take MPAs, particularly in nearshore areas, will likely be met with incredible resistance by those most affected by the closure, often commercial fishers (Suman, Shivlani, and Milon 1999; McClanahan, Davies, and Maina 2005; Christie and White 2007; Mascia, Claus, and Naidoo 2010; McCay and Jones 2011). A more realistic approach is to recognize and positively respond to stakeholder resistance by incorporating their views into discussions. The goal of MPA design within an EBFM framework should be to "enhance fisheries, reduce conflicts, and protect resources" (Bohnsack 1993, 63), regardless of initial size or seasonality. An MPA that is supported by fishers and managers meets Bohnsack's last two goals of reducing conflict and, through the support of fishers, protects resources from illegal fishing. Initial MPA success will in turn garner and build more support and compliance of fishers

(McClanahan et al. 2006; Cinner et al. 2009), who will over time come to recognize the MPA as their own (McClanahan, Davies, and Maina 2005).

Yet, despite such common-sense advice, fisheries management has few success stories (Hilborn 2007a, 2007c; Murawski 2010). In the case of MPAs, the failure to achieve management goals has been attributed to both an institutional ineffectiveness as demonstrated by a lack of sufficient enforcement, monitoring, and community support (Salas et al. 2007), and, returning to the 20-30% no-take criteria, the inability to generate support for and then successfully protect a sufficiently large enough area so that ecosystem services and functions are not jeopardized (Boersma and Parrish 1999; Roberts, Halpern, et al. 2001). MPA failures, like other ineffective regulatory strategies, may result from not being precautionary enough (Russ 2002; Rosenberg 2007). Failures can arise from underestimating the amount of uncertainty remaining in the system, being slow to respond and adapt to system effects, having a “mismatch” between the size and character of a fishery and the scale of management (Crowder et al. 2006), and being hampered by competing political wills of stakeholders and officials during their design and implementation (Hilborn et al. 2001; Oracion, Miller, and Christie 2005). While the precautionary approach has generally meant to respect an incomplete understanding of a marine system's ecology and ecosystem functionality, particularly with regards to EBFM frameworks, it can also mean management failure to fully recognize political limitations and underestimate resistance from the fishing community, and how motivations to be non-compliant have their own uncertain impacts. Understanding and responding to FEK, as demonstrated through fisher resistance in the face of any particular regulatory tool or management approach, can help lower the risk of management failure because of an alienated, unsupportive fishing community.

5.1.2 Marine Protected Areas in Small-Scale Fisheries

An EBFM-designed MPA affords protections to both targeted and non-targeted marine populations and their habitat. As such, MPAs are different from traditional regulatory controls such as single-stock management strategies that focus on reducing total fishing effort or allowable catch to some prescribed level, and may therefore be more appropriate for successfully managing SSFs (Johannes 1998; Schrank 2007). Such controls, for example, on describing allowable catch, are data-dependent, which is likely to be unavailable or of limited value or scope in SSFs. Functioning MPAs, because they support ecosystem resilience (Pikitch et al. 2004), also are less likely than other regulatory controls to be undermined by a failure to recognize regime shifts (Folke et al. 2004), or cascading trophic effects (Scheffer, Carpenter, and de Young 2005), that result from secondary impacts of overfishing by re-organizing the remaining community.

MPAs, as part of a holistic EBFM approach, can also provide much-needed help in improving limited enforcement capabilities of SSF management. This is because MPAs are discretely defined spatially, while SSF fishing effort and markets in SSFs tend to be highly dispersed in both space and time (Salas et al. 2007). Fishers vary effort and ground selection daily or even several times over the course of one trip. MPAs, separate from other mechanisms, allow enforcement to focus in specific areas.

MPAs are thought to be capable of returning ecosystem service benefits, including fisheries that are several orders of magnitude larger than the loss of the area to fishing (McClanahan and Mangi 2000). Even at scales smaller than the prescribed 20% coverage, properly designed and implemented MPAs and networks of MPAs have improved fishery stocks and been central to maintaining healthier marine communities and generating community support and the development of alternate economic opportunities (Roberts, Halpern, et al. 2001; Heyman, Carr, and Lobel 2010).

Finally, the development of MPAs allows managers and fishers a rare opportunity to work together. In data-poor SSFs, fishers possess the necessary knowledge and experience to identify grounds that serve as EFH and that should receive priority for protection. Through their FEK, fishers can recognize specific sites of productivity within a larger fishing ground that are otherwise impossible to locate without first-hand knowledge of where and when to fish because of the small scale of exploitation (Johannes, Freeman, and Hamilton 2000). Indeed, FEK and fishing behavior may be one of the greatest tools that data-poor SSFs possess for developing and successfully implementing a management framework. Given their highly detailed yet qualitative nature, FEK may best be applied in the development of MPAs.

5.1.3 Overcoming Uncertainty with Fishers' Ecological Knowledge and Behavior

The general hesitation of scientists and managers to predict ecosystem responses or speculate on fisheries-related issues with limited data or understanding (Berkes 2003; Rosenberg 2007), has led to a disconnect between those who develop regulations (i.e. fisheries managers) and those who work within their confines (i.e. fishers). Fishers rely daily on their FEK to overcome and deal with uncertainty on stock densities, movement, and changing physical conditions, motivated by economic and social demands. As a result, fishers have little difficulty in responding to changing conditions on a multitude of scales. Conversely, fisheries managers tend to view uncertainty over seasons, years, and even longer (Hughes et al. 2005), as such long time scales are required to adequately examine ecosystem responses to such regulatory tools like gear reductions, seasonal closures, or MPAs (Russ 2002; Sadovy and Domeier 2005). The frequent result is that management lacks the agility to adaptively react at fisher-operant scales (Wilson 2006; Worm et al. 2009).

Managers who value FEK recognize that the process of learning it provides a means for them to more fully engage with fishers (Silvano and Valbo-Jørgensen 2008; O'Donnell, Pajaro, and Vincent 2010). FEK provides new avenues of discourse between fishers and managers and strengthens the political underpinnings and impacts of EBFM (Agrawal and Benson 2011). Fully engaged fishers develop a sense of ownership of the resource and tend to cooperate with other fishers and with managers (Drew 2005; Grafton 2005), thereby limiting effects of open-access behaviors that encourage over-fishing (Peterson and Stead 2011).

Yet, encouraging fisher participation in regulatory development provides fishers an opening to disrupt the system or tilt it toward their own needs (Silver and Campbell 2005; O'Donnell, Pajaro, and Vincent 2010). Given fishers' unique perspective and historic hesitancy to work with resource scientists or managers, engaging them in regulatory design is both critical for the long-term success of those regulations, but also fraught with opportunities to fail. This study addresses how to increase fisher participation in EBFM without corrupting the system, embracing flawed benchmarks or biased standards, or working in a manner that excludes other stakeholder groups (Jentoft 2000).

5.1.4 Utilizing Fishers' Ecological Knowledge to Examine Regulatory Design

As a case study for testing the ability of incorporating FEK into regulatory design, this research focuses on the coral reef fishery of St. Croix, U.S. Virgin Islands. St. Croix has long supported a vibrant, locally-important, small-scale commercial fishery focused on queen conch (*Strombus gigas*), Caribbean spiny lobster (*Panulirus argus*), and several families of demersal and pelagic fishes (Kojis 2004), particularly scarids (parrotfishes), serranids (groupers and hinds), lutjanids (snappers), and balistids (triggerfishes). Developing and implementing a sustainable management program within the territory, however, has been hindered by a lack of suitable fisheries data and the necessary support for proposed regulations by stakeholders (NOAA 2005, 2007a; CFMC 2009a). While resource managers and fisheries scientists have spent much of the past several years developing management directives to have U.S. Caribbean fisheries comply with the Magnuson-Stevens Fisheries Conservation and Management Act (NOAA 2007b) , little meaningful work has been done apart of Kojis’ (2004) fisher census to assess the potential of including territorial fishers and their unique knowledge and skill sets into the deliberative process. Each island’s fishery through the U.S. Caribbean is unique (Kojis 2004), with the commercial fishery in St. Croix being predominantly scuba-assisted. Fishers dive throughout the open seasons for conch and lobster while opportunistically spearfishing. While not nearly as dominant a gear as in St. Croix’s sister island of St. Thomas, several fishers use traps to capture deep reef fish species (Agar et al. 2005), and many troll for pelagic fishes, particularly mahi (*Coryphaena hippurus*).

What becomes immediately clear from the perspective of fisheries management programs is that the multi-gear, multi-target Crucian fishery cannot be managed using single-gear and single-species approaches (CFMC 2009). St. Croix's commercial fishery has been characterized as open-access, having endured unsustainable fishing gear selection, coupled with low compliance with existing regulations, weak enforcement, and an ineffective licensing mechanism that serves to exacerbate issues of overfishing (DPNR 2004b; Kojis 2004; DPNR 2005b). When these issues are added to the ongoing losses of EFHs throughout the U.S. Virgin Islands (Rogers and Beets 2001; Nemeth, Whaylen, and Pattengill-Semmens 2003; DPNR 2005b; Miller et al. 2006; NOAA 2008; Rothenberger et al. 2008), the risk of commercial fishery extirpation in St. Croix is real.

The existing regulatory regime on St. Croix is viewed by managers and numerous stakeholder groups, especially commercial fishers, as ineffectual in dealing with the myriad concerns facing the island's marine resources (Gordon and Uwate 2002; DPNR 2005b). Short on enforcement capabilities, St. Croix's fisheries management is dependent upon fisher compliance and self-enforcement, yet fishers remain largely excluded from aiding in the planning and review of research, data, and regulatory development. While this exclusion is often self-inflicted by fishers too pessimistic with the state of their fishery and regulations, there are other factors that prevent fishers from fully engaging, e.g. geographic issues (i.e. meetings are not always held on St. Croix) and economic issues (i.e. attending the meetings prevents them from fishing at the same time).

This study uses a case study approach focused on the management of mutton snapper (*Lutjanus analis*) in St. Croix to examine if FEK-based regulatory alternatives will be supported publicly. Mutton snapper is presently managed through a seasonal MPA and a 'no fishing / no-possession' closed season during its vulnerable spawning season. To do so, the opinions and FEK of commercial fishers on existing regulations and possible alternatives are evaluated through interviews. These data are then synthesized into a Discrete Choice Model (DCM), which was administered to stakeholders and the public to test the null hypothesis:

H_0: Existing regulatory structures focusing on the management of the mutton snapper fishery in St. Croix will be broadly preferred by fishery stakeholders and the general public.

H_1: Existing regulatory structures focusing on the management of the mutton snapper fishery in St. Croix will not be broadly preferred by fishery stakeholders or the general public. Instead, regulatory alternatives, designed with the input of fishers and incorporating their LEK, will be preferred.

Rejecting the null hypothesis would suggest that existing management is not broadly supported by the public.

5.2 Methodology

5.2.1 Fisher Interviews and Open-Ended Surveys

Researchers identified fishers for this research by initially seeking well-respected and known fishers viewed as leaders within the fishing community, and then expanding the sample group through the "snowball technique" (Biernacki and Waldorf 1981). Participating fishers provided verbal and written permission prior to being included into the study, following institutional standards and protocols. Each participating fisher was first interviewed in a structured survey format followed by open-ended discussions. A total of 42 fishers participated in the survey, approximately 26% of all current licensed commercial fishers.[1]

The structured survey presented 68 statements that fishers scored along a Likert scale from 1 (strongly disagree) to 5 (strongly agree). These Likert scores were then aggregated for review and served as the basis for semi-structured, open-ended interviews focused on St. Croix's commercial fishery, its productivity and health, and management. Interviews ran from 10 – 90 minutes and required from one to five sittings to be

[1] Unpublished data provided by DPNR's Division of Environmental Enforcement, 28 January 2012. Of 160 licensed fishers, 70 are considered to be full-time fishers with no other major source of income or employment. Of the interviewed fishers, 36 identified themselves as full-time fishers.

completed. The interviews followed a basic format of introductory questions that focused on elements of commercial fishing that was of concern or important to fishers. The interviews were allowed to branch off from there, with the fisher leading the course and direction of the interview.

Interviews were audio recorded unless the participating fisher declined. Researchers also took notes of both the fisher's words and their own thoughts that merited further inspection throughout the interview or immediately after completing the interview. All recordings and notes were then transcribed and analyzed for site and fishing method descriptions and comments on issues pertaining to St. Croix's fishery and management program. Finally, a keyword content analysis was performed on transcriptions and researcher interview notes. Keywords and phrases associated with Likert statements were searched for in the text, and sorted into themed groups (e.g. spatial-, temporal-, gear-focused management recommendations) defined through a content analysis approach (Neuendorf 2002).

5.2.2 Discrete Choice Model Design and Administration

A map-based Discrete Choice Model (DCM) was developed utilizing interview data and the direct participation of fishers. Choice models presented hypothetical regulatory frameworks for the management of *L. analis* that relied on spatial, temporal, and gear-based restrictions in unique combinations. Final model elements presented a range of regulatory alternatives for the management of *L. analis* during their critical spawning season, and incorporated spatial closures (both seasonal and permanent), closed seasons, varying boundaries to include or exclude federal waters, and gear restrictions focused on spearfishing and fish traps. For each scenario, the model presented two alternatives in a pair-wise fashion, and included explanatory notes to inform the respondents. In each scenario, one alternative represented a "fisher preferred" option, built around survey and interview data, while the other differed from a "fisher preferred" option in one important manner. The "fisher preferred" option was built by incorporating fishers' recommendations identified during Likert surveys and interviews, and reflected a combination of spatial-, temporal-, and gear-based regulatory tools. The other option in each pair differed in at least one of these regulatory areas in such a manner that, overall, the option reflected a "not fisher preferred" framework. DCM respondents were not told which option in each pair was the "fisher preferred" option.

The final DCM survey was composed of eight questions that incorporated fourteen variations of an EBFM management plan for *L. analis*. The survey was distributed both in-person and via the internet. In addition to the discrete choice survey questions, respondents answered various demographic and fisheries management questions. The survey was administered 1 May – 15 July 2011.

5.2.3 Discrete Choice Model Analysis

Results from the in-person and web-based DCM were aggregated, sorted by residency, and tested for significance with statistical software (SPSS v17.0). Results were analyzed to assess the existing management framework against other alternatives, both those preferred and not preferred by fishers. Finally, alternatives were compared against each other to evaluate the likely support of fishers and the general public for the range of regulatory tools.

5.3 Results

5.3.1 Fisher Interviews and Open-Ended Surveys

Summary descriptive data for 42 interviewed St. Croix commercial fishers are presented in Table 5-1. The mean age of interviewed fishers was 39 ± 14 years and they had a mean of 20.1 ± 13.9 years experience as commercial fishers. A large majority of the fishers use scuba (86%) and hook and lines (90%) and about half (52%) report using fish and lobster traps. Compared to a fisher census conducted by Kojis (2004), the 2010 sample group is smaller, younger, and more heavily invested in scuba-aided fishing, although the island fleet remains generally multi-gear. The primary concern fishers have is improving fisheries enforcement. Currently, DPNR’s Division of Enforcement divides its time in a number of both terrestrial and marine areas. Fishers proposed in interviews establishing a dedicated fisheries enforcement division, given the numbers employed, and the amount of fish landed, sold, and consumed locally. Table 5-2 shows Likert scores for the various statements that formed the starting point for open-ended discussions about issues of St. Croix's fisheries and their management.

Table 5-1 Comparison of Interviewed Fishers from this Study and Kojis (2004)

	Min	Max	This Study Mean ± SD (n = 42 fishers)	Kojis 2004 Mean ± SD (n = 217 fishers)
Age	20	72	39.0 ± 13.6	51.4 ± 12.5
Years Commercial Fishing	5	55	20.1 ± 13.9	21.7 ± 12.6
No. Scuba Tanks Used Daily per Fisher[a]	0	9	3.5 ± 1.8	6.4 ± 2.9
No. Fish Traps Used Daily per Fisher[b]	0	100	8.6 ± 18.3	21.6 ± 20.9

a. Kojis (2004) calculated that 38% (n = 83 fishers) of interviewed fishers in St. Croix used scuba gear to assist in spearfishing, net tending, and hand collecting lobster and conch. Of these 83, 80 used scuba gear year-round. All 42 fishers interviewed for this study used scuba to assist in fishing and collecting lobster and conch.

b. Kojis (2004) calculated that 24% (n = 52 fishers) of fishers in St. Croix used fish traps. There were 22 fishers (52%) interviewed for this study who used fish traps.

According to Likert survey results, Crucian fishers are primarily concerned with issues of habitat quality, illegal fishing, poaching, and water pollution. They are concerned that they will face more regulations in the coming decade, but are confident that the island's nearshore fishery won't be closed within 10 years. They recognize that fishery management needs improving, and strongly agree with the ideas that local data is crucial for management and that fisher-scientist partnerships should be brought alongside other management approaches.

5.3.2 Discrete Choice Model Design and Administration

Fishers proposed nine regulations in interviews (Table 5-3). These elements were scored through content analysis techniques (Neuendorf 2002), and categorized as spatial, temporal, or gear-focused. Recommendations were kept simple and enforceable, which fishers believe will lead to increased compliance.

Table 5-2 Likert-Scaled Fisher Responses (n = 42) on Status of St. Croix's Fisheries (1 - highly disagree to 5 - highly agree)

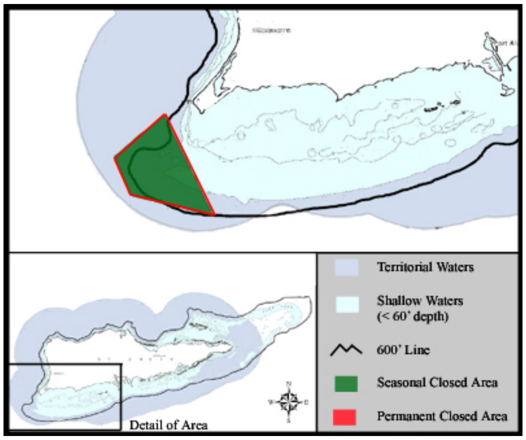
STATEMENT (1 = Highly Disagree to 5 = Highly Agree)	**Mean ± SD (n = 42)**
Habitat quality is important to your fishery.	4.7 ± 0.6
Utilize local science and data for your fishery.	4.6 ± 1.1
Establish closed seasons with the input of fishers.	4.6 ± 1.3
Form partnerships with scientists for managing your fishery.	4.6 ± 0.8
Water pollution impacts your fishery.	4.3 ± 1.0
Illegal fishing / poaching is a major issue for your fishery.	4.3 ± 0.6
Your fishery will have more regulations in 10 years.	4.1 ± 0.6
Establish closed seasons based on species reproductive needs.	4.1 ± 1.8
Establish closed areas with the input of fishers.	4.0 ± 1.9
Enforce existing marine protected / no-take areas.	3.7 ± 1.8
Seasonal closures increase catch of stocks the rest of the year.	3.5 ± 0.9
Coastal development impacts your fishery.	3.5 ± 1.4
Marine reserves increase catch outside their boundaries.	3.4 ± 1.0
Seasonal closures prevent overfishing of managed stocks.	3.3 ± 1.2
Overfishing is a major issue in your fishery.	3.1 ± 1.1
Fishery regulations are fair to fishers.	3.0 ± 1.0
Fishery regulations help prevent overfishing.	2.8 ± 0.8
Marine reserves prevent overfishing.	2.6 ± 1.1
Your fishery will be closed in 10 years.	2.4 ± 1.1
Continue to manage fisheries the way they are currently managed.	2.1 ± 2.0
Expand marine protected / no-take areas.	1.5 ± 1.8
Your fishery needs more fishery regulations.	1.5 ± 0.8

Table 5-3 Fisher Recommendations for Improving Management in St. Croix

Focus Area	Fisher – Aggregated Recommendations	Score (max = 42)
Spatial	Regulations must protect critical habitat for stocks.	41
	Seasonal area closures are preferable to permanent closures because of stock behavior.	38
	Larger seasonal area closures are preferred if the other option is a smaller permanent closure.	27
Temporal	Closed seasons should be developed with an understanding of stock life history stages.	42
	The moratorium on issuing new commercial fishing licenses should be maintained.	36
	Expand no-possession rules to include purchasers, restaurants, hotels, and freezing catch.	34
Gear	Reduce trap by-catch and habitat impacts by enforcing trap design and escape hatches.	31
	Reduce fish trap numbers by setting a maximum number a fisher can use.	22
	Reduce by-catch and habitat impacts by enforcing regulations against scuba-aided net fishing.	13
General	Improve local enforcement of regulations.	42
	Reduce illegal and unreported commercial fishing effort.	42
	Simplify regulations in a straightforward manner.	38

5.3.3 Discrete Choice Model Analysis

There were 140 responses to the DCM survey, with 54 (39%) being completed by current or past residents of St. Croix. The mean age of the respondent was 33 ± 7.5 years, and the mean residency of those who have lived on St. Croix was 4.1 ± 5.6 years. Eight paired alternatives were presented by the DCM (Figure 5-1 through 5-8) from fishers' recommendations and instructions to test straightforward regulatory scenarios.



Option A

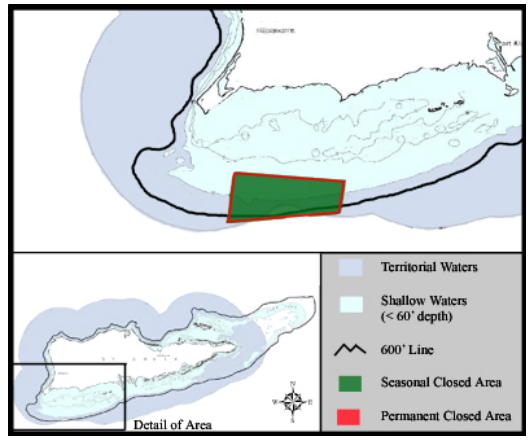
A seasonal area closure within territorial and federal waters from 1 March – 30 June annually to protect a historical fish spawning aggregation site of mutton snapper.

A seasonal no-possession regulation within all federal and territorial waters from 1 April – 30 June annually for the capture, possession, or sale of mutton snapper.

A = 70 total respondents (50%)

A = 31 St. Croix respondents (57%)

A = 39 Non-Resident Respondents (45%)



Option B

A seasonal area closure within territorial waters from 1 March – 30 June annually to protect a historical fish spawning aggregation site of mutton snapper.

A seasonal no-possession regulation within all federal and territorial waters from 1 April – 30 June annually for the capture, possession, or sale of mutton snapper.

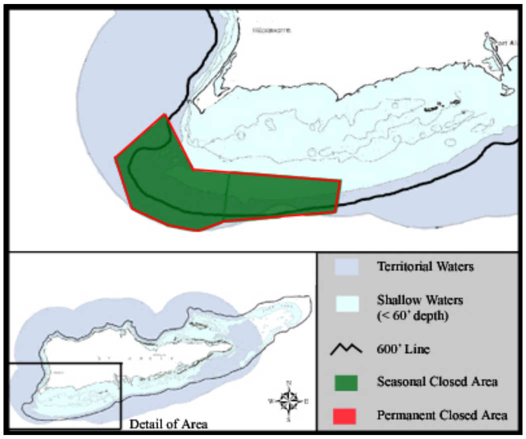
FISHER PREFERRED

B = 70 Total Respondents (50%)

B = 23 St. Croix Respondents (43%)

B = 47 Non-Resident Respondents (55%)

Figure 5-1. DCM Pair 1 - EBFM-styled regulations vs. existing regulations.



Option A

A seasonal area closure within territorial and federal waters from 1 March – 30 June annually to protect a historical fish spawning aggregation site of mutton snapper.

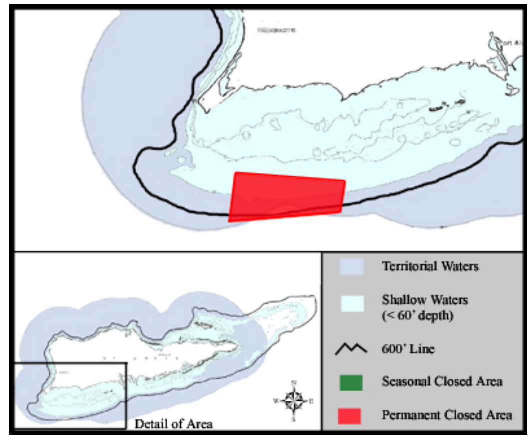
A seasonal no-possession regulation within all federal and territorial waters from 1 April – 30 June annually for the capture, possession, or sale of mutton snapper.

FISHER PREFERRED

A = 97 Total Respondents (69%)

A = 37 St. Croix Respondents (69%)

A = 60 Non-Resident Respondents (70%)



Option B

A permanent area closure within territorial and federal waters to protect a historical fish spawning aggregation site of mutton snapper.

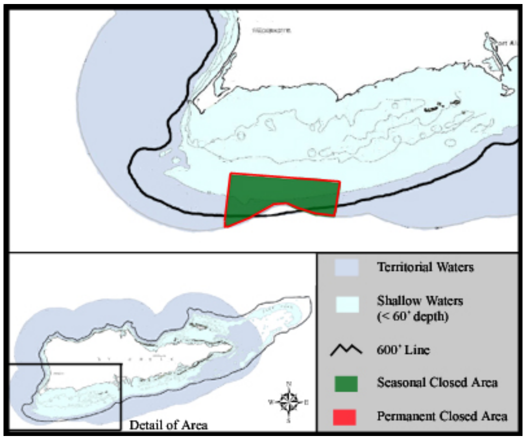
A seasonal no-possession regulation within all federal and territorial waters from 1 April – 30 June annually for the capture, possession, or sale of mutton snapper.

B = 43 Total Respondents (31%)

B = 17 St. Croix Respondents (31%)

B = 26 Non-Resident Respondents (30%)

Figure 5-2. DCM Pair 2 - Expanded seasonal EBFM-style regulations vs. permanent area closure.



Option A

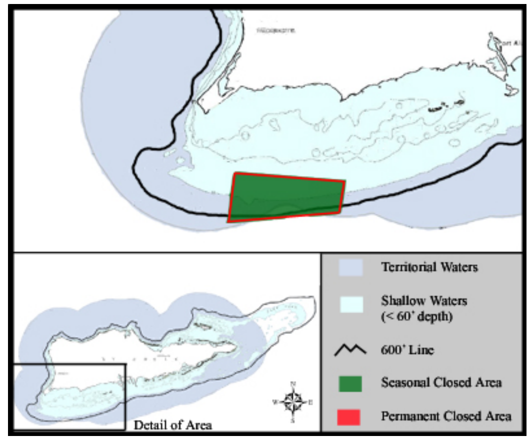
A seasonal area closure within territorial waters from 1 March – 30 June annually to protect a historical fish spawning aggregation site of mutton snapper.

A seasonal no-possession regulation within all federal and territorial waters from 1 April – 30 June annually for the capture, possession, or sale of mutton snapper.

A = 27 Total Respondents (19%)

A = 14 St. Croix Respondents (26%)

A = 13 Non-Resident Respondents (15%)



Option B

A seasonal area closure within territorial and federal waters from 1 March – 30 June annually to protect a historical fish spawning aggregation site of mutton snapper.

A seasonal no-possession regulation within all federal and territorial waters from 1 April – 30 June annually for the capture, possession, or sale of mutton snapper.

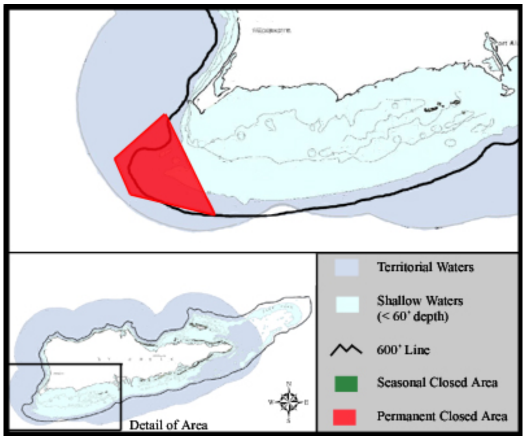
FISHER PREFERRED

B = 113 Total Respondents (81%)

B = 40 St. Croix Respondents (74%)

B = 73 Non-Resident Respondents (85%)

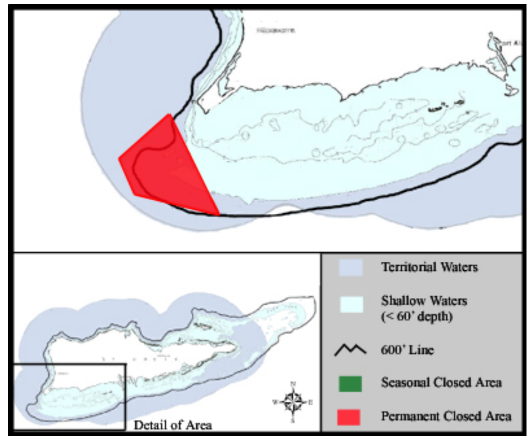
Figure 5-3. DCM Pair 3 - Territorial vs. joint territorial-federal management.



Option A

A permanent area closure within territorial waters for fish traps only to protect a historical fish spawning aggregation site of mutton snapper.

A seasonal no-possession regulation within all federal and territorial waters from 1 April – 30 June annually for the capture, possession, or sale of mutton snapper.



Option B

A permanent area closure within territorial waters for scuba-assisted spearfishing only to protect a historical fish spawning aggregation site of mutton snapper.

A seasonal no-possession regulation within all federal and territorial waters from 1 April – 30 June annually for the capture, possession, or sale of mutton snapper.

FISHER PREFERRED

A = 94 Total Respondents (67%)

A = 36 St. Croix Respondents (67%)

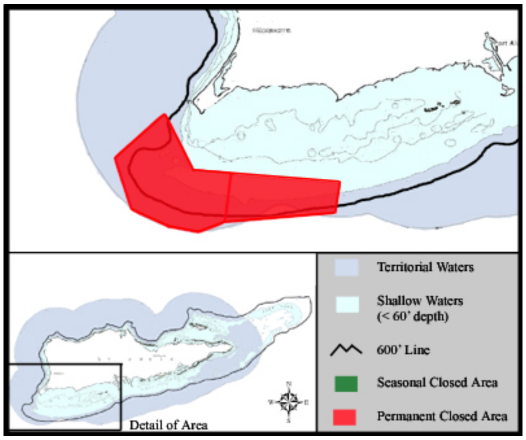
A = 58 Non-Resident Respondents (67%)

B = 46 Total Respondents (33%)

B = 18 St. Croix Respondents (33%)

B = 28 Non-Resident Respondents (33%)

Figure 5-4. DCM Pair 4 - Trap fishing prohibitions vs. spearfishing prohibitions.



Option A

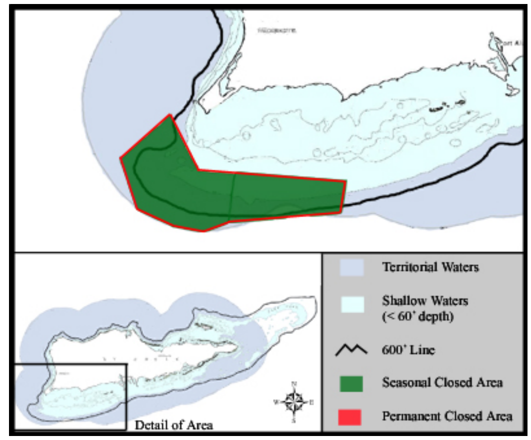
A permanent area closure within territorial and federal waters to protect a historical fish spawning aggregation site of mutton snapper.

No regulation for the capture, possession, or sale of mutton snapper caught outside of the permanent area closure.

A = 32 Total Respondents (23%)

A = 17 St. Croix Respondents (31%)

A = 15 Non-Resident Respondents (17%)



Option B

A seasonal area closure within territorial and federal waters from 1 March – 30 June annually to protect a historical fish spawning aggregation site of mutton snapper.

A seasonal no-possession regulation within all federal and territorial waters from 1 April – 30 June annually for the capture, possession, or sale of mutton snapper.

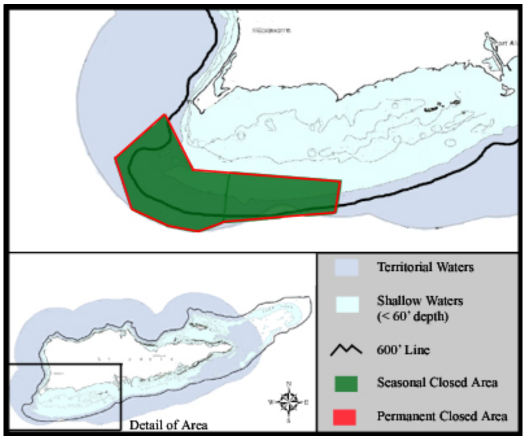
FISHER PREFERRED

B = 108 Total Respondents (73%)

B = 37 St. Croix Respondents (69%)

B = 71 Non-Resident Respondents (83%)

Figure 5-5. DCM Pair 5 - Permanent area closure no regulations against possession vs. seasonal area closure with no-possession prohibitions.



Option A

A seasonal area closure within territorial and federal waters from 1 March – 30 June annually to protect a historical fish spawning aggregation site of mutton snapper.

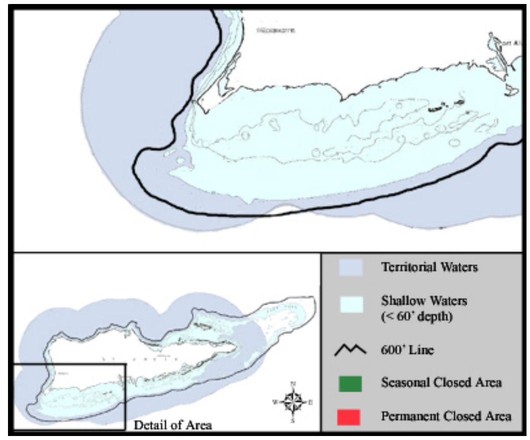
No regulation on the capture, possession, or sale of mutton snapper caught outside the seasonal area closure.

FISHER PREFERRED

A = 93 Total Respondents (66%)

A = 32 St. Croix Respondents (59%)

A = 61 Non-Resident Respondents (71%)



Option B

A seasonal no-possession regulation within all territorial and federal waters from 1 March – 30 June annually for the capture, possession, or sale of mutton snapper.

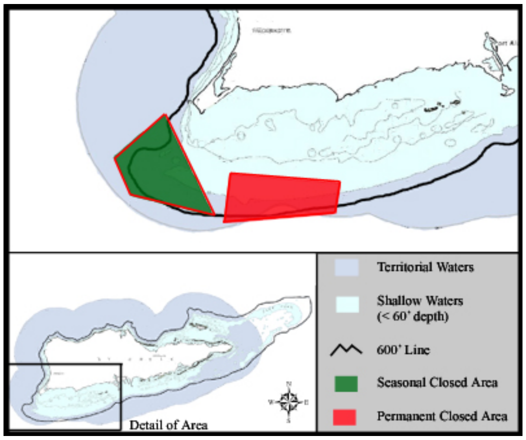
No permanent or seasonal area closures in territorial or federal waters.

B = 47 Total Respondents (73%)

B = 22 St. Croix Respondents (41%)

B = 25 Non-Resident Respondents (29%)

Figure 5-6. DCM Pair 6 - Seasonal area closure with no regulations against possession vs. seasonal no-possession regulations.



Option A

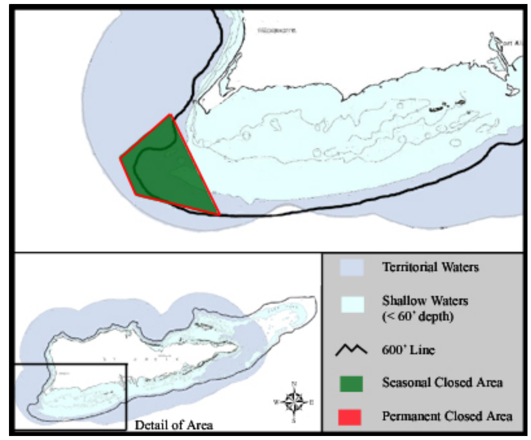
A permanent area closure within territorial waters and a seasonal area closure within territorial waters from 1 March – 30 June annually to protect a historical fish spawning aggregation site of mutton snapper.

No regulations for the capture, possession, or sale of mutton snapper caught outside of either area closure.

A = 52 Total Respondents (37%)

A = 19 St. Croix Respondents (35%)

A = 33 Non-Resident Respondents (38%)



Option B

A seasonal area closure within territorial waters from 1 March – 30 June annually to protect a historical fish spawning aggregation site of mutton snapper.

A seasonal no-possession regulation within all federal and territorial waters from 1 April – 30 June annually for the capture, possession, or sale of mutton snapper.

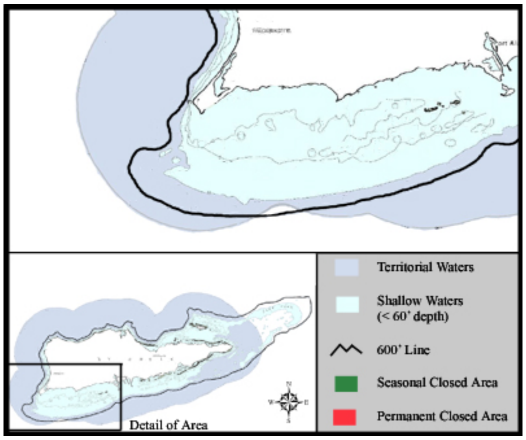
FISHER PREFERRED

B = 88 Total Respondents (63%)

B = 35 St. Croix Respondents (65%)

B = 53 Non-Resident Respondents (62%)

Figure 5-7. DCM Pair 7 - Networked permanent and seasonal area closures with no regulations against possession vs. seasonal area closure and no-possession prohibitions.

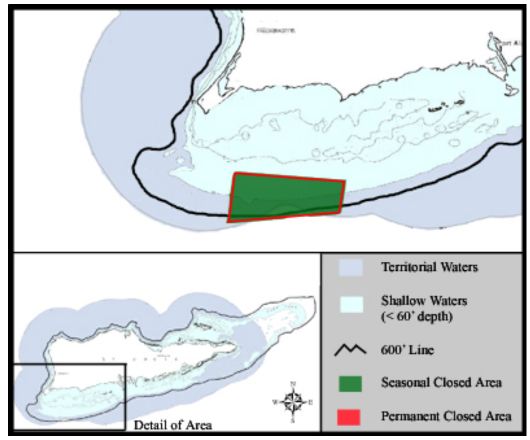


Option A
No territorial or federal regulations regarding the capture, possession, or sale of mutton snapper.

A = 6 Total Respondents (4%)

A = 3 St. Croix Respondents (6%)

A = 3 Non-Resident Respondents (3%)



Option B
A seasonal area closure within territorial and federal waters from 1 March – 30 June annually to protect a historical fish spawning aggregation site of mutton snapper.

A seasonal no-possession regulation within all territorial and federal waters from 1 April – 30 June annually for the capture, possession, or sale of mutton snapper.

FISHER PREFERRED

B = 134 Total Respondents (96%)

B = 51 St. Croix Respondents (94%)

B = 83 Non-Resident Respondents (97%)

Figure 5-8. DCM Pair 8 - Unregulated open-access fishery vs. seasonal closure and seasonal no-possession regulations.

Table 5-4 presents summary demographic statistics for respondents. Fifty-seven percent of the respondents indicated that they were "unfamiliar" with fishery regulations, while 44% were uncertain in describing the health of its reefs, and 45% were uncertain in describing the health of its fishery. Despite this uncertainty, 51% of respondents believed that overfishing was having a measurable effect on the current health of St. Croix's reef fish populations, while only 4% believed that commercial fishers were

Table 5-4 Summary Demographic Statistics for Discrete Choice Respondents (n = 54 St. Croix residents, 86 non-residents).

Demographic Indicator	Statistic
Mean Age (yrs.)	33 ± 7.5
Percentage of Respondents Currently a Resident of St. Croix	29%
Percentage of Respondents Who Have Lived on St. Croix	39%
Mean Residency on St. Croix (yrs.)	4.1 ± 5.6
Percentage unfamiliar with fishery regulations in the U.S. Virgin Islands	57%
Percentage describing health of St. Croix's reefs as "somewhat" or "very" unhealthy.	44%
Percentage uncertain in describing health of St. Croix's reefs.	43%
Percentage describing health of St. Croix's fisheries as "somewhat" or "very" unhealthy.	44%
Percentage uncertain in describing health of St. Croix's fisheries.	45%

fishing in a responsible manner (Table 5-5). Other statements in Table 5-5 suggest that respondents believe that the island's reef fish populations are unhealthy.

The first test conducted by the DCM set was to examine public support for the existing regulatory structure for managing *L. analis* in St. Croix against similar regulations where the MSSAA shifted to the shelf elbow (Figure 5-1), and an unregulated open access fishery (Figure 5-8). While respondents were unable to identify a real difference between options in Figure 5-1, they agree with fishers and overwhelmingly support some spatial regulation as opposed to none, with 134 individuals selecting Option B in Figure 5-8 (96%).

Two DCM pairs exclusively tested differences in spatially based regulatory tools. Fisher-preferred alternatives in Figure 5-3 (Option B) and Figure 5-6 (Option A) were both greatly preferred by respondents. Fishers prefer protecting fish during their spawning season in those fish spawning areas through no-take MPAs rather than general prohibitions on their capture and possession that, to fishers, is overly broad spatially and doesn't address accidental capture. Fishers also are skeptical about the ability of territorial agencies to properly manage the fishery, and prefer some federal oversight. In Figures 5-4 and 5-7, both of these issues are greatly supported by public respondents,

Table 5-5 Public Responses: "What three factors do you think are most responsible for the current health of St. Croix's reef fish population?"

Statement	**Total (n = 140)**
Overfishing by commercial fishers	72
Coral reef habitat loss	58
Coastal pollution	53
Inadequate enforcement	51
Illegal / Unlicensed fishing	50
Mangrove habitat loss	30
Poor land-use practices	27
Recreational overfishing	20
Lionfish invasion	11
Commercial fishers fishing responsibly	6
Meaningful enforcement	6
Recreational fishers fishing responsibly	5
Healthy mangrove habitat	5
Meaningful closed seasons	4
Sensible land-use practices	4
Healthy coral habitat	3
No-Take Marine Protected Areas	2
Successful commercial licensing program	1

with 81% of respondents selecting for the inclusion of federal oversight, and 66% selecting for the spatial MPA-based management strategy. Support for both fisher-preferred options were lower with St. Croix residents than they were more generally.

Two DCM pairs tested differences in temporally based regulatory approaches. For political and economic reasons, fishers prefer shorter, seasonal closures to permanent closures. In Figure 5-2, respondents selected the fisher-preferred Option A 69% of the time, preferring a large seasonal closure to a smaller permanent closure. In Figure 5-5, 73% of respondents selected a large seasonal closure with associated no-possession regulations compared to an identically sized permanent closure.

One DCM pair (Figure 5-4) tested differences in gear-based regulations. Fishers in St. Croix greatly prefer reducing fish trap fishing when faced with the alternative of reducing spearfishing. The DCM respondents (67%) agreed, selecting a permanent prohibition on trap fishing at the southwestern shelf elbow of St. Croix over a similarly-located closure that affected only spearfishing.

One DCM pair (Figure 5-7) examined regulatory complexity, an important consideration for fishers in St. Croix who wish for simple, straightforward regulations that can be readily reviewed to see any benefit. Faced with a regulatory framework that differed primarily by level of complexity, 63% of respondents selected the fisher-preferred Option B that reflected a less complex framework.

5.4 Discussion

5.4.1 Fisher Perspectives to Managing St. Croix's Fisheries

Nine common themes were touched upon through many fisher interviews that could be used to review existing regulations and develop alternatives (Table 5-3). As mentioned above, fishers primary concerns were not so much improving regulations, but rather enforcement, and ensuring that regulations in place were simple and straightforward. Both of these concerns were based upon an overriding sense that DPNR was ineffective as the lead fisheries management agency in St. Croix, as seen in this quote from a long-time commercial fisher:

> " I can’t even go near [the MSSAA] and people think I’m stealing fish. And does DPNR know if it’s working? Nobody even knows if it's working. Is it working? Are there more snapper out there now? Nobody knows! You tell me!” (12 May 2010)

The content analysis successfully sorted keywords and phrases into three categories (Table 5-3), with many fisher recommendations overlapping into two or all three. Foremost, fishers do want to see any more permanent closures in St. Croix, despite the ease with which they could be implemented and the supporting literature highlighting the benefits of permanent no-take reserves ((Bohnsack 2000; Fernandes et al. 2005; Kellner et al. 2007; McClanahan et al. 2007). Permanent closures are politically difficult, and the last instance of implementing such a reserve in St. Croix, with the expansion of the Buck Island Reef National Monument, was pursued and adopted with little regard for its impact on the St. Croix's fishing community:

> "They closed Buck Island because they didn't like the fishers. Just went and closed it all. And most of it is in 7000 feet [2100 m] of water. What's that protecting? They should have at least asked us [the fishers]. That'd help with compliance. But no. And guess what? I bet people still fish it every night." (14 May 2010)

Fishers largely associated needed closures with protecting spawning populations (Table 5-2, Likert = 4.1 ± 1.8), and believe that fishers possess much more relevant information than local managers and so should be approached when designing closures (Table 5-2, Likert = 4.6 ± 1.3). Indeed, fishers are strongly confident in their FEK and ability to describe St. Croix's marine environment and its functionality comprehensively:

> "There are at least three aggregations I know on the south shore. Maybe the same one but maybe they move, or maybe it’s a couple different groups spawning, making babies. And the last time we showed DPNR, they closed it [the MSSAA in 1993] and never bothered to go back to see if the closure was in the right spot or was doing anything good. Nobody [is going] to take DPNR nowhere [to show other spawning aggregation sites]. Let them find it. They the managers, right? We the fishers.” (6 May 2010)

Interestingly, the results presented of the 2010 surveys are consistent with previous studies (Gordon and Uwate 2002; Kojis 2004; DPNR 2005b), suggesting that the views of fishers in 2010 have not changed much over at least the past decade and that regulations and resource managers have not successfully addressed major issues in St. Croix's fisheries.

In meetings in 2009 and 2010, the CFMC made it clear that managers were beginning to move away from single-stock management plans and to ecosystem-level approaches. This movement toward EBFM is a clear indication that declines in marine resources and their critical habitats are not solely due to fishing. Indeed, in discussing EBFM proposals during interviews, fishers showed a clear understanding of the goal of any regulation and even suggested potential outcomes, which further refined the process of building the DCM range of alternatives. Fishers suggested that their participation in regulatory development was necessary because it would give them a voice to protect their interests and livelihood while reducing the impacts of illegal fishing and habitat loss, two important EBFM goals. Looking over the coming years, they believe that the number of regulations will increase, as will the potential of permanent closures. Such regulations would be disastrous for their ability to make an honest livelihood, they say. And most ominously, from the perspective of improving management and reaching sustainable fishery goals, is that commercial fishers say that many of their fellow fishers would be forced to fish illegally as they lack the training, skills, or interest in transitioning to another livelihood or industry. This sobering reality illustrates the importance of quantifying perspectives and testing them as regulatory alternatives.

5.4.2 Comparing Fisher Preferences to Public Preferences

In examining FEK and its potential to improve fishery regulations at a meaningful, positive level, it is important to remain cognizant of the pitfalls with conflating fisher biases with observed results (O'Donnell, Pajaro, and Vincent 2010). One practical purpose of the methodology developed by this work is to simultaneously compile and analyze FEK, including the biases of the fishers, without then transferring those biases into the DCM design. It is important to be able to identify these biases and preferences against their FEK, behaviors, and future opportunities as commercial fishers, but not to limit the range of options available to respondents in the DCM. The DCM approach, while simple, reduces the opportunity to capture and misrepresent fisher bias through the straightforward, Option A / Option B structure that presents similarly weighted alternatives against each other.

Results from the DCM showed that non-fishers and non-residents show clear similarities in their preferred management alternatives to fishers. Both groups sense that fisheries management, particularly enforcement, needs improvement in St. Croix. While fishers expressed this directly during interviews, both resident and non-residents were able to reveal this both in their DCM selections and also during follow-up survey questions (Table 5-5). While it is likely that, as Table 5-5 shows, that both residents and non-residents believe overfishing to be occurring, the incentive to approach and review fisheries enforcement is one that would be applauded not only by residents but also by those fishers who do work to fish within the management framework and are being materially affected by ongoing illegal, unlicensed, and unreported fishing.

5.4.3 Recognizing the Value of Simplicity of Scale in Fisheries Management

Fishers and all other respondents concur that simple regulations are always preferred over more complex ones. As seen in Figure 5-7, both fisher and non-fisher, resident and non-resident respondents selected a simple regulatory framework of a nested seasonal MPA within a larger no-fishing / no-possession regulation (fisher-preferred Option B) against a network of two MPAs sited ostensibly to protect *L. analis* throughout a larger area during its spawning season. St. Croix residents, in particular, preferred Option B at twice the rate of Option A.

Spearfishing can be a devastating fishing method, removing the largest, most fecund individuals and keystone species (Bell 1983; Chapman and Kramer 1999). In contrast, however, accidental mortality of untargeted or immature stocks is often lower than for other less selective gears such as traps (Frisch et al. 2008). Scuba-aided fishing, more generally, is depth limited because of the risks associated with repetitive and deep diving, leading to a refugia effect for many species at depths beyond the usual range of diving (Tupper and Rudd 2002). Management should recognize and respect the fact that commercial fishing in St. Croix is primarily done by spearfishing, and should seek to encourage its wise application, rather than forcing fishers to adopt other gears that increase the complexity and range of uncertainty in the fishery. Through education, training, and positive support for responsible fishing practices, the negative aspects of spearfishing can be reduced. Such support can take the form of regulatory tools, as well as economic and social incentives that encourage wiser and safer spearfishing.

The strong preference to avoid permanent closures (Figures 5-2, 5-5, and 5-7) has merit beyond simply acknowledging the need of fishers to continue to fish. This result reflects the difficult and complex reality of managing SSFs. While the benefits of permanently closed MPAs has been shown (Nemeth 2005), overcoming resistance by the fishing community to closures is difficult and seasonal closures, if supported and complied with by fishers, should be seen as a practical management alternative.

There are associated ecological effects with closures. Closing areas permanently concentrates effort into a smaller area, which would have the perverse effect of encouraging the targeting of smaller and younger fishers, perhaps even undersized, immature individuals. To meet demand, a larger number of fishes would be needed, thereby increasing the risk that a fished reef becomes extirpated. Managers would also be wise to recognize the socioeconomic and political implications of a permanent closure against perceived ecological benefits. Permanent closures require substantial enforcement, a major issue for St. Croix, and the loss of grounds further burdens the already tenuous relationship between fishers and managers. It may be practical to build up a positive relationship with smaller closures coupled with efforts to reduce impacts of coastal pollution and eutrophication that have little to do with fishing effort but are critical elements of an EBFM framework. Such a pragmatic approach would do much to reach out to the commercial fishing community and seek their support for EBFM goals, rather than attempting to step around their positions and impose permanent closures.

With each step, management complexity increases yet the hope of meeting management goals becomes more distant. And although the above scenario is portrayed in theoretical terms, the exact situation occurred recently in St. Croix with the management of queen conch. Following evidence of unsustainable harvesting throughout much of the past decade, federal managers proposed a multi-year conch fishing moratorium (Freehill 2007a), that would potentially extend ten years. Yet, the moratorium was averted, and instead a 50,000-lbs. quota for St. Croix that triggered a closed season through the conch's summer breeding season was enacted in time for the 2008 season (NOAA 2007a). These regulations require greater oversight, monitoring, and enforcement by managers, which again addresses the need for improved enforcement and cooperation between fishers and managers. And as recent catch reports have shown, conch landings have been significantly reduced since 2008, although not exceeding the 50,000-lbs. quota remains a concern (NOAA 2010).

5.5.4 Recognizing FEK and Fisher Perceptions on Fisheries Health

As seen in follow-up questions (Tables 5-4 and 5-5), the public simultaneously believes overfishing is the major cause for decline in reef fish populations, yet they are uncertain about the health of those same stocks. It becomes hard to recognize management successes against the larger perceptual condition that overfishing must be redressed. Yet, as seen in the 'fisher-preferred' options in Figures 5-1 through 5-8, fishers tend to have a much greater understanding of those issues and strategies that can affect fisheries. In particular, fishers recognize the value of larger seasonal MPA closures (Figure 5-2) that more closely reflect their FEK on the location of *L. analis* spawning areas. In conversations with researchers, fishers believe the center of *L. analis* spawning aggregation may exist to the west of the presently zoned area, but is encompassed by the seasonal area closure plotted in Option A of Figure 5-2. This knowledge is supported by evidence is supported by observations that aggregations tend to form along reef-edge elbows adjacent to steep shelf walls Kobara and Heyman (2010). Indeed, Kojis and Quinn (2011), hypothesized that the *L. analis* spawning aggregation exists at the western end of the southern shelf edge. While fishers are not particularly interested in relocating the MSSAA to the shelf elbow, from an EBFM standpoint, they understand the value of protecting spawning grounds (Table 5-2), and would be open to a review of its location, particularly if they were involved meaningfully and throughout the process, including participating in a scientific study of the area, and, during discussions, were able to fully share their thoughts and opinions.

5.5.5 Recognizing How FEK Can Improve Management Focus and Needs

As recognized throughout all sections of this research, the overarching perception is that St. Croix's fisheries suffer from insufficient enforcement. Fishers and respondents prefer maintaining federal oversight in the management of *L. analis* for St. Croix waters (Figure 5-4). This suggests a lack of faith in the capabilities of DPNR and its territorial authority to successfully manage and monitor its fisheries. Commercial fishers gave a number of reasons for supporting regulations that invite federal oversight. Foremost, fishers reported a general lack of trust and fairness in dealing with DPNR and a strong belief that the federal CFMC council, based in Puerto Rico, was more responsive and, despite ongoing complaints on a lack of St. Croix-relevant fisheries data, more receptive to fisher concerns. Fishers also recognized the pragmatic reality that greater federal oversight would come along with increased funding for research and management specifically on St. Croix (DPNR 2005a).

This result is a sign that DPNR in particular needs to review their own work in managing the fisheries of St. Croix and, more generally, the U.S. Virgin Islands. A loss of public and stakeholder confidence can undermine positive accomplishments, and can lead to calls for federal take-over in management, as was made by the St. Thomas Fisherman's Association (STFA 2009). DPNR will remain the face of management and enforcement in the U.S. Virgin Islands and so efforts must be made to change both this negative perception and their ability to set and reach management goals. Given the current status of incomplete and poorly applicable datasets for St. Croix, DPNR should consider re-establishing working relationships with Crucian fishers, seeking to incorporate FEK in a positive manner to immediately address areas of uncertainty, improve management and the build collaborative partnerships for management.

5.5 Conclusion and Recommendations

This research seeks to examine how FEK can be used in a review of management regulations for *L. analis*, particularly during its vulnerable spawning season, and then develop and test a methodology for examining its impact and value for presenting FEK-based regulatory alternatives to a wider audience. FEK offers valuable information for management in otherwise data-poor fisheries that suffer from insufficient management and enforcement. As a first step, this research compiles and tests FEK-based regulatory alternatives for support by other stakeholder groups. Support for these alternatives by other stakeholder groups, particularly those who may view commercial fishers in an unfavorable light, suggests FEK can be successfully used to manage fisheries. Furthermore, this research comes at a time where calls to include fishers into regulatory discussions and development are growing in the U.S. Caribbean by both federal (NOAA 2007b; CFMC 2009a; NOAA 2009; CFMC 2010) and territorial agencies (DPNR 2004a, 2005b). Yet, these efforts remain in their infancy. The value of applying FEK cannot be underestimated in terms of generating workable regulatory mechanisms that carry stakeholder support (Johannes, Freeman, and Hamilton 2000; Silvano and Valbo-Jørgensen 2008; Heyman 2011). The responsible fisheries scientist must work to bridge the divide and draw fishers into taking a more active role if fisheries are to remain open and move toward becoming sustainable.

This research has shown that FEK can be thoughtfully incorporated into fisheries management alternatives to better understand ecosystem functions that remain better understood by fishers than by scientists or managers. Additionally, seeking out and learning from FEK allows managers to reach out to fishers in an equitable fashion. Fishers can rely on their FEK to provide a forum from which they can be heard during regulatory discussions and reviews. FEK can raise issues or concerns voiced by fishers and generate support by other stakeholder groups. By conducting a number of concurrent studies, surveys, and interviews, this research combines ecological and socioeconomic studies into an integrated analysis of St. Croix's fisheries and regulatory structure. This analysis has yielded the following management recommendations:

5.5.1 Recommendation 1 - Territorial and federal agencies must improve enforcement.

Fishers and the general public have identified fishery enforcement efforts as needing major improvement if St. Croix's fisheries are to have a chance of being sustainably fished. Enforcement should focus on illegal, unlicensed fishing and the targeting of immature fishes, lobsters, and conch, and of fishing at spawning sites. In order to generate the necessary funds to operate a dedicated fisheries enforcement division, researchers suggest DPNR review current commercial fishing license fees, and coupled with pursuing federal monies dedicated to enforcement, adjust licensing structures so that such an enforcement division is self-funded. Researchers have found that full-time commercial fishers would support a great increase, perhaps as much as $1000 a year in licensing fees to weed out part-time or occasional fishers who disrupt their market share. In return for increased licensing fees, fishers should receive additional tax easing similar to those they currently receive for boat fuel costs. Both the license and the special tax status should be tied to reporting requirements designed to further improve accurate, local landings data collection.

5.5.2 Recommendation 2 - Territorial and federal agencies must research ecosystem changes as they impact fisheries.

Fishers and the general public believe that St. Croix's nearshore ecosystem is deteriorating, a point supported by recent research (NOAA 2008; Rothenberger et al. 2008). This deterioration has negative effects on fisheries and fishers, who face the consequences of declining stocks caused by conditions, such as coastal pollution and eutrophication of coral reefs that are beyond their control. Large-scale issues that need to be continually addressed include reducing the environmental impact along St. Croix's industrialized south shore by improving waste water treatment facilities, requiring the

Hovensa Oil Refinery[2] to better manage accidental spills and effluent discharge, and redesigning the waste-water discharge outfall at Cruzan Rum Factory to be further off-shore and deeper. At smaller scales, St. Croix should seek to improve road and land construction to minimize coastal erosion and pollution from entering the ocean during storm and wind events.

5.5.3 Recommendation 3 - Management should reconsider the placement of the MSSAA.

Relevant literature and interviews with fishers suggests that mutton snapper spawning may be occurring further west and potentially outside the MSSAA boundary, near the island's shelf elbow below the area known as Sandy Point. Researchers should work to fully characterize St. Croix's southwestern shelf and locate the center of spawning aggregation activity, as the capture of 100 snappers in 2009 and 2010 suggest an aggregation remains active (Kojis and Quinn 2011). Protecting this spawning aggregation is important, particularly so if the site is also used by other fishes for their own spawning, or if St. Croix's mutton snapper population is maintained through self-recruitment. Given that researchers have thus far been unable to positively identify and characterize the extant *L. analis* spawning aggregation, there exists a tremendous opportunity for researchers and fishers to work cooperatively, find the spawning aggregation, characterize the site and spawning population, and then together sit down and discuss workable regulations that both embrace EBFM and remains fair to those fishers working to establish and maintain a sustainable *L. analis* fishery in St. Croix.

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[2] On 18 January 2012, Hovensa LLC announced that it would be ceasing refinery operations by 1 March 2012, and converting the refinery into an oil storage facility. The closure, which would directly cause the loss of at least 2000 jobs in St. Croix, was deemed necessary by the parent companies of Hess Oil and Venezuelan-owned Petroleos de Venezuela, because of spiraling losses associated with the oil-powered refinery, which was the third largest, by capacity, in the United States in 2010.

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VITA

Name: Liam Morgan Carr

Address: 810 Eller O&M Bldg. TAMU 3147 College Station, TX 77843

Email Address: liammorgancarr@gmail.com

Education: Yale University, 2001

M.F.S., School of Forestry & Environmental Studies

University of Southern California, 1999

B.S., Biological Sciences

B.A., Environmental Studies

Publications: Carr, L.M. and W.D. Heyman. *In prep*. "It's about seeing what's actually out there": quantifying fishers' ecological knowledge and biases in a small-scale commercial fishery as a path towards co-management. *Ocean & Coastal Management.*

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Awards: 2012 Knauss Fellow - NOAA Office of Communications & External Affairs

2010 VI-EPSCoR Fellow

2008 The Nature Conservancy Sustainability Program

2007 Texas A&M University Excellence in Teaching Award