Diving dangerously: Exploring human health and resource trade-offs of unsafe dive profiles in a Caribbean (Grenada) dive fishery

By

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Dedication

To all the small-scale fishers and divers of the developing world

who risk their lives daily in one of the world's

most dangerous occupations

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Abstract

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Dive fishers around the world employ compressed air diving to harvest marine living resources in the quest for livelihoods. Fishers can suffer catastrophic health consequences while targeting these fisheries resources that are in states of overexploitation. While the health effects of diving fisheries have been well documented, the underlying drivers of unsafe dive practices remain unaddressed. Applying an ethnographic approach, this study examined why fishers undertake unsafe dive profiles in the Caribbean Spiny Lobster (*Panulirus argus*) and Queen Conch (*Lobatus gigas)* small-scale dive fishery of Grenada. Semi-structured, qualitative interview data from fishers were supplemented by direct and participant observation, and analyzed using a thematic, grounded theory approach. Factors promoting unsafe dive practices, vulnerabilities in the fishery as well as dive related risk factors were identified. Unsafe dive profiles are largely driven by uncertainties in the market for catch, which are also influenced by changes in the ecology of the fishery. Three approaches exist for fisheries managers: reduce vulnerabilities affecting fishers, address underlying drivers, and mitigating diving risk factors. Under appropriate management and socio-economic regimes, it is not inconceivable that the Grenadian dive fishery could be a safe, sustainable and economically viable model.

Keywords: Dive fishery; SCUBA; decompression illness; co-management; Grenada

List of Abbreviations

AGE	Arterial Gas Embolism
CADF	Compressed Air Dive Fishery
CFO	Chief Fishery Officer
DCI	Decompression Illness
DCS	Decompression Sickness
DON	Dysbaric Osteonecrosis
FDF	Freedive Dive Fishery
FEK	Fishers Ecological Knowledge
HBOT	Hyperbaric Oxygen Therapy
GDP	Gross Domestic Product
GPS	Global Positioning System
NIS	National Insurance Scheme (Grenada)
PADI	Professional Association of Diving Instructors
REB	Research Ethics Board
SCUBA	Self Contained Underwater Breathing Apparatus
SSF	Small Scale Fisheries

Glossary

Barewind Freediving

Bends Serious or severe form of DCI or Type II DCS that may include instances of AGE. Generally, results in immediate hospitalization or following ineffective attempts at self-medicating.

Blow a tank May refer to a dive as each tank corresponds to one dive. May also refer to a tank that's been entirely drained of air.

Bubbles Refers to mild symptoms of DCI such as skin rashes, limb pain or Type I Decompression Sickness. Generally self-medicated with analgesics and bed rest.

Goods The catch that is sought. May refer to animals yet to be or already harvested.

In company To travel *in company* refers to boats travelling together to and from dive sites, fishing near one another. A safety net in case of accidents, lost-at-sea incidents or engine failures.

Keep up man The captain, responsible for driving the boat but also for following or keeping up with the diver's bubbles as the primary means of tracking them.

Lambi / Lambie Queen Conch (*Lobatus gigas*).

Market To find or have market is to seek or have a buyer for *goods* or catch

Seamoss Refers to the macroalgae *Gracilaria spp.* as well as the drink from which it is derived.

Shares The equal proportioning of profits among crewmembers and boat owner. If the diver is also the owner of the boat, the diver receives two shares.

Tide Refers to prevailing water currents encountered while diving, dictated by changing tides.

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Chapter 1: Introduction

A. Management problem and context

The application of compressed air diving in the quest for marine living resources significantly aggravates the dangers of fishing in what has long been considered one of the world's most dangerous occupations (Ben-Yami, 2000; Drudi, 1998; Vann et al., 2011). Compressed air diving, using Self Contained Underwater Breathing Apparatus (SCUBA) or surface supplied air systems, poses unique physiological risks to the human body not observed in other types of fishing (Blatteau et al., 2015; Eriksson et al., 2012; Vann et al., 2011).

Dive fisheries, detailed in subsequent chapters, have been documented around the world where they largely target benthic, high-value species of crustaceans, molluscs and echinoderms but also fish, for both consumption and ornamental use (Ehrhardt, 2006; Eriksson et al., 2012; Forman, 2005; Halim, 2002; Gold et al., 2000; Lepawsky & Wong, 2001; Nayar et al., 2009; Ruffez, 2008; Westin et al., 2005). Like many global fisheries, the stocks that are subject to dive fisheries, may be at risk of overexploitation (CRFM, 2011; Stoner et al., 2012; Pauly & Zeller, 2016; Toral-Granda et al., 2008). Diving decompression injuries and barotraumas [1] have been well documented in dive fisheries, at times with

[1] Pressure related injuries

catastrophic consequences for fishers (Barratt & van Meter, 2004; Eriksson et al., 2012; Lepawsky & Wong, 2001; Ruffez, 2008).

The physiological implications of diving mean that dive fisheries represent a unique system in which human physiology is inextricably linked to the fishing effort exerted by the individual. Consequently, human physiology and health, can be thought of as being connected to the sustainability of the resource. Allison et al. (2012) posit that fishers' vulnerability must be addressed if they are to be "effective and motivated resource stewards" (p.19), as must our understanding where these vulnerabilities are situated in relation to the fishery. Similarly, fishers who risk their lives for a livelihood are conceivably facing their own vulnerabilities and unlikely to be pre-occupied with resource conservation. Therefore, managing dive fisheries requires that both human health and the state of the resource be taken into account. While the health consequences of dive fisheries have been well established, non-medical perspectives of these fisheries remain largely unexplored and unaddressed (Barratt & van Meter, 2004; Blatteau et al; 2015; Eriksson et al., 2012; Gold et al., 2001).

Dive fisheries are being recognized as complex fisheries systems where dive behaviour and decompression sickness relationships are poorly understood (Huchim-Lara et al., 2015). To this complexity, a socio-ecological dimension must be considered. This study fills a gap in our knowledge of dive fisheries by examining the Caribbean Spiny Lobster (*Panulirus argus*) and Queen Conch (*Lobatus gigas*) dive fishery in Grenada.

This case study was selected as data exists from an epidemiological study of diving in this fishery, conducted by Forman (2005). Forman's study showed high-rates of dive related morbidity and mortality, but no management interventions were undertaken to address this situation. This study attempts to understand some of the complexities that are inherent in a dive fishery, through an ethnographic description of the practice, beyond research on the incidence of diving injuries (Russell, 2006). This paper introduces the research question and scope (Chapter 1) before providing a review of dive fishery systems including dive physiology and ecological considerations. The methodological approach is described (Chapter 3) and followed by an ethnographic account of diving practices in the Grenadian dive fishery (Chapter 4). The results of the study and discussion of the data in Chapter 5 provide the backdrop for the recommendations and conclusions presented in Chapter 6.

B. Research question and scope

In the Grenadian dive fishery, Forman (2005) found that fishers performed unsafe dive profiles and suffered high rates of diving injuries with 81% of divers reporting one or more injury. These findings are in line with diving practices found in other dive fisheries (Eriksson et al., 2012; Lepawsky & Wong, 2001; Ruffez, 2008). Barratt and van Meter (2004) characterized the dive profiles of Nicaraguan lobster divers as *provocative*, meaning divers provoked the dive injuries.

The term *dive profile* describes the complex set of characteristics of a dive – the submersion and subsequent ascent using compressed air – that have an influence on human physiology and the risk of being subject to dive-related injuries. The factors that comprise a dive profile include depth and duration of a dive, rate of descent/ascent, rate and extent of air consumption, intervals between dives, and number of repetitive dives conducted (Huchim-Lara et al., 2015; Tetzlaff & Thorsen, 2005). In the context of this study, dive profile is also used to include the nature of the equipment used, training acquired to dive, the level of effort exerted underwater, sea conditions in which diving in undertaken and the state of the stock(s) being harvested, as all these factors relate to dive safety.

Fishers are aware of the risks involved in diving, either from personal experience or from observing other divers subjected to injuries and even death, but continue to dive despite this knowledge (Eriksson et al., 2012; Forman, 2005). Given the risks faced, the consequences suffered and awareness of the dangerous practice that fishers undertake, the primary research question of this study asks***: what are the underlying drivers of unsafe dive profiles in the Grenadian dive fishery?*** In other words, this paper is concerned with why fishers engage in what we may refer to as dangerous diving practices. Understanding these drivers may help determine what suitable management strategies might be best placed to address both diver health and sustainable management of the fishery.

Sub-questions that this research addresses are:

i. How do fisher's understanding of the state of the resource affect their dive behaviour?

ii. How do divers understand and manage personal risk?

iii. What type of management approaches may result in safer diving practices?

The scope of the research is on the small-scale, multi-species SCUBA dive fishery in the Eastern Caribbean island state of Grenada, Carriacou and Petit Martinique (Figure 1). This paper will use Forman's (2005) study on the prevalence of decompression illness in the fishery, and it will supplement it with the consideration of socio-ecological dimensions of the fishery.

Figure 1 Map of Grenada showing communities included in the study. ArcGIS Online, 2016.

i. The small-scale Grenadian dive fishery

Grenada, Carriacou and Petit Martinique is a small (344 km^2) tri-island English-speaking nation in the southern end of the Caribbean archipelago with a population of approximately 105’000 inhabitants (Figure 1; SOFRECO, 2012). The primary driver of the economy is the tourism sector, with agricultural export of spices also playing an important role in foreign exchange earnings (Kairi Consultants, 2008).

The Grenadian fishery, as an economic sector, represents approximately two percent of the Gross Domestic Product (GDP), and is one of the few sectors to experience growth in recent years (Kairi Consultants, 2008; SOFRECO, 2012). It employs 1,500 fishers (of which approximately 1,125 are fulltime) with up to 3800 people employed in the fishery when associated actors are taken into account (SOFRECO, 2012). Employment in the fishery sector is dominated by poor members of society, and is both an important socio-economic activity and contributor to food security (Kairi Consultants, 2008; McConney, 2003). The Caribbean Spiny Lobster (*Panulirus argus*) and Queen Conch (*Lobatus gigas*) fisheries targeted by divers represent a small portion of the overall national fishery in terms of employment and landings, but are important high-value earning species (McConney & Baldeo, 2007; SOFRECO, 2012).

Most dive fisheries referenced here, including the one under consideration in this study, are small-scale, developing world fisheries. Understanding the context of small-scale fisheries (SSF) in the developing world provides a point of departure for framing the challenges highlighted in the Grenadian dive fishery. The concept of small-scale fisheries have long eluded a precise definition, however, there are key characteristics that describe small-scale fisheries, not all of which may be present in all fisheries (Berkes et al., 2001; Pauly & Charles, 2015). These include but are not limited to (adapted from Andrew et al., 2007; Berkes et al., 2001; Salas et al., 2007):

- Multi-species, multi-gear and multi-fleet fisheries;
- Labour intensive methods; low capital investment;
- Diversity in landing sites;
- Significant provision of protein;
- Socio-economic vulnerability.

While the points listed above provide an indication for the reader, their characterization is less important than what they represent. Ultimately, SSFs represent diverse and highly complex socio-ecological systems (Andrew et al., 2007; Charles, 2011). Globally, small-scale fisheries are considered significant contributors to food security, livelihoods and human development providing benefits for tens of millions of people (Andrew et al., 2007). Furthermore, small-scale fisheries are dominant features in fisheries of the tropical, developing world in which dive fisheries are found where significant management challenges persist (Berkes et al., 2001; Mahon, 1997; Parsram, 2012). Small-scale fisheries of the Eastern Caribbean face significant challenges from a management perspective where fisheries departments suffer from deficiencies in structural arrangements and the ability to deal with emerging crises (Mahon & McConney, 2005; Salas et al., 2007). As a result, they are not able to perform as the large fisheries departments of the developing world on which they were originally modeled (Mahon, 1997). The inability to reliably monitor landing data on conch and lobster at numerous sites which is largely lacking in the Grenada dive fishery is an example of such limitations (Mohammed & Linhop, 2015).

Chapter 2: Literature Review

A. What are Dive fisheries?

There has been no systematic review of dive fisheries in a global context[2]. Equally, there is no universal term for diving in fisheries in the literature, nor has there been a treatment of its definition. There is variance in the terminology found in the literature where the practice has been referred to as *diving fisheries*, *artisanal diving,* and *scuba-assisted fishing* (Carr & Heyman, 2014; Madrigal & Maquez, 2014; Matsuda, 2008).

The term *dive fisheries* is proposed and a working definition of what the term encompasses follows. In its simplest form, dive fisheries may be defined as the submersion of fishers for harvesting marine living resources. The primary attribute to consider is human submersion where the actual methods used for harvesting (e.g. speargun) or the species targeted are secondary to the definition.

It is useful to further subdivide the term dive fisheries to reflect two distinct diving techniques: freediving or breathold diving and compressed air diving. This distinction reflects both the technological evolution in fisheries from freediving to compressed air diving, and the physiological risk and harvest efficiency that differentiates the two techniques. Despite this subdivision in terminology, it is

[2] Bassett, Winkler, Chin, Allison & Joo (in preparation)

worth noting that in some fisheries, fishers may employ both methods interchangeably depending on need (Fernandez-Boan, 2013; Madrigal & Marquez, 2014).

Freedive Fisheries (FDF) are fisheries in which fishers rely on breathold techniques, or freediving, to harvest marine living resources. While freediving is not without risk, the occurrence of decompression sickness (DCS) is still a matter of debate and seems to be of most concern where freedivers conduct deep dives repetitively over several hours (Lemaitre et al., 2009; Schipke et al., 2006). In freedive fishers, notable instances of dive related injuries, possibly decompression sickness, has been recorded in pearl divers of French Poylnesia and the Ama divers of Japan (Lemaitre et al., 2009). At extreme limits, freediving fishers may conduct multiple dives repetitively over several hours to depths of 100ft/30m+ for 3 to 4 minutes at a time (Schipke et al., 2006).

Compressed Air Dive Fisheries (CADF) involve the use of Self Contained Underwater Breathing Apparatus (SCUBA) and surface supplied diving. Compressed air diving evolved significantly for mass use with the refinement of the aqualung during the Second World War by Emile Gagnan and Jacques Cousteau, the precursor of modern recreational SCUBA (Acott, 1999). Compressed air allows fishers to maximize their time and range underwater, thus increasing fishing efficiency, particularly vis-à-vis freediving (Basurto, 2006; Lindfield et al., 2014; Sabetian & Foale, 2006). Compressed air diving is associated with the physiological risks of decompression sickness and other pressure related injuries (Vann et al., 2011). In unregulated fisheries, these risks result in significant health consequences for dive fishers, as discussed below (Blatteau et al., 2015). Compressed air diving is generally accepted to be a technological evolution from freediving practices in fishing (Basurto, 2006). In fact, management controls for fisheries often ban compressed air systems because of their potential to deplete resources (Tewfik & Béné, 2004; CRFM, 2011). Following the catastrophic results in its lobster fishery where hundreds of fishers were killed or severely injured, Nicaragua remains perhaps the only jurisdiction that has enacted legislation specifically to address the health implications of dive fishing (Ehrhardt, 2006). The need to address both the human and efficiency consequences of diving is starting to be recognized in some fisheries (Pakoa & Bertram, 2013). Unless otherwise specified, subsequent reference to the term dive fishery in this paper refers to CADF.

A traditional recreational SCUBA setup (Figure 2) consists of a metal air cylinder (tank) held by an inflatable jacket worn by the diver, which is used to regulate buoyance (referred to as a Buoyancy Control Device or BCD). Air is supplied by a two-stage regulator, the first stage is attached to the tank cylinder and reduces high-pressure air from the tank (first stage) to breathable low-pressure air for the diver to consume via a mouthpiece (second stage; Egstrom, 1993). Additionally, one high-pressure port on the first stage allows a hose to be connected to a gauge so the diver can determine how much air is in the tank (Egstrom, 1993).

This regulator consists of two mouthpieces from which the diver breathes (one acting as an emergency spare), a low-pressure inflator to operate the BCD, and a gauge console for monitoring depth and air pressure (Egstrom, 1993). In dive fisheries, this setup may vary widely in configuration and may be as rudimentary as a tank loosely harnessed by rope to the diver with a regulator fitted solely with single mouthpiece supplying air to the diver, with no ability to know the diving depth or available air supply (Forman, 2005).

Figure 2 Divers filling a conch basket using SCUBA at approx. 85ft /26m. Note the effect of strong currents on divers and their bubbles. Photo by author.

Surfaced supplied systems (Figure 3) in dive fisheries are also known as compressor or hookah diving (Blatteau et al., 2015). In this variation, a simple air compressor based on a boat supplies air to a diver along a small-bore tube that may extend up to 300ft/100m (Gold, 2001). Unlike commercial diving applications where stringent equipment standards are required, compressors used in dive fisheries are usually rudimentary and employ equipment not initially designed to supply breathable air. The use of compressors to supply air to the divers, designed for nail guns or painting, are not uncommon (Basurto, 2006; Blatteau et al., 2015; Chin at al., 2015). They are usually fitted with a rudimentary air tanks which act as a brief air reserves should the compressor fail. These air tanks may be made from repurpose beer kegs, for example (Basurto, 2006). Intake of exhaust into the air supply from the compressor motor, compressor failure or running out of fuel are all added complications of compressor diving in fisheries (Chin et al., 2015; Wong, 2001; Xu et al., 2001).

Figure 3 Hookah diving compressors in the Mexican Yucatan. Note beer keg modified as reserve air tank and supply hose from which divers breathe on the left. Walter Chin, UCLA, with permission.

In order to understand dive fisheries as more than a method of fishing and begin to consider them as fishery systems in their own rights it is important to define them beyond the technologies they employ. Dive fisheries are also characterized by their social, ecological and economic context in which they are found. Examples include social dynamics and inter-fisher competition in diving effort in the Turks and Caicos freedive fishery where fishers are found to make complex choices in deciding they type of species they target (Béné & Tewfik, 2001). The ecology of target species also play a vital role in understanding fisher behavior, dive effort and harvest efficiency, particularly for cryptic reef species such as octopus (Madrigal & Marquez, 2014). A definition of dive fisheries should also consider the elements unique to this type of fishing, particularly with regards to the socio-economic implications of injured divers and the ecological impact of diving on resources. The evidence suggests that diving can be labeled as a small-scale fishery (SSF) activity. The main problems resulting in high morbidity and mortality are largely connected to a developing country context where diving occurs in unregulated settings (Barratt & van Meter, 2004; Blatteau et al., 2015; Ehrhardt, 2006; Eriksson et al., 2012; Gold et al., 2000a; Westin et al., 2005). Comparatively, developed world dive fisheries are generally governed by commercial working safety regulations (e.g. Australia, New Zealand; Prince et al., 2008; New Zealand Government, 2013).

While most dive fisheries take place in the ocean, dive fishing has also been documented in freshwater environments (Mesquita & Isaac-Nahum, 2015). Furthermore, dangerous diving practices in the developing world have also been documented in illegal gold mining operations, notably in the Philippines where hookah diving was adapted from fishing practices in the region and largely employs children as they are able to fit into tight, flooded mine shafts (Human Rights Watch, 2015). Dive fishers are also known to use their skills to engage in other activities, such as salvaging scrap metal from sunken shipwrecks in Vietnam (Blatteau et al., 2015).

B. What is known about dive fisheries?

Compressed air dive fisheries have been documented around the world. Table 1, provides a non-exhaustive list of where they have been recorded. Dive fisheries target a multitude of species, predominantly benthic, and mostly high value species. These include various species of lobsters, sea cucumbers, sea urchin, conch, abalone, scallops, and octopus (see references in Table 1). Other target species include fish for consumption such as reef fish and pelagics (Madrigal & Marquez, 2014; Naranjo & Salas, 2012; Nayar et al., 2009); ornamental fish (Halim, 2002; Stevenson et al., 2011); live bait (Anderson, 1996) and sea turtles (Nayar et al, 2009; Prada et al., 2006).

Table 1 Dive fisheries around the world and their primary target species.

Country/Region	Target Catch	Sources
Australia	Abalone	Wong (2001)
Canada	Sea urchin	Miller (2008)
Chile	Octopus	Defeo & Castilla (1998)
Colombia	Caribbean Spiny lobster, queen conch, fish	Prada et al. (2006)
Costa Rica	Green lobster, parrotfish	Madrigal & Marquez (2014)
East Africa	Sea Cucumber	Toral-Granda et al. (2008); Eriksson et al. (2012)

Country/Region	**Target Catch**	**Sources**
Eastern Caribbean	Spiny Lobster	CRFM (2011)
Ecuador (Galapagos)	Sea cucumber	Westin et al. (2005)
Grenada	Spiny lobster, queen conch	Forman (2005)
Jamaica	Spiny Lobster	Monnereau & Pollnac (2012)
Mexico	Scallops, Spiny Lobster	Basurto (2006); Huchim-Lara et al. (2015)
New Zealand	Abalone	Government of New Zealand (2013)
Nicaragua	Spiny Lobster	Daw (2007); Ehrhardt (2006)
Pacific Island States	Sea Cucumber	Ruffez (2008)
Philippines	Fish (consumption and ornamental)	BBC (2013); Halim (2002); Miclat et al. (1991)
South Korea	Not specified 1.	Sakong (1998)
Thailand	Lobster, seashells, shrimp, squid	Gold et al. (2000a)
Turkey	Sponge	Çimşit (2001)

Country/Region	Target Catch	Sources
Vietnam	Sea cucumber, metal recovery from shipwrecks	Blatteau et al. (2015)
United States	Ornamental fish	Stevenson (2011)

As indicated above, dive fisheries employ either SCUBA or hookah systems. The actual method of fishing used by divers may include hand harvesting (e.g. for conch & sea urchin; Nayar et al., 2009), wire loops (lobster; Forman, 2005), spear guns (fish; Carr & Heyman, 2012; Lindfield et al., 2014), underwater nets (fish; Miclat et al., 1991), cyanide (ornamental fish; Halim, 2002) or prying tools (pen shells; Basuro, 2006).

Based on the above cited literature, the depths to which fishers will dive vary greatly but generally range from very shallow 18/ft5.5m in the Mexican Seri scallop fishery (Basurto, 2006) to as deep as 165ft/50m in Zanzibar's sea cucumber fisheries (Eriksson et al., 2012)[3]. Diving may occur within proximity of fishing communities, or may involve more prolonged travel to distant fishing grounds (Basurto, 2006; Daw 2007; Defeo & Castilla, 1998; Eriksson et al., 2012). Diving is also employed to manage aquaculture systems (Smart & McCartney, 1990). SCUBA and hookah are also used in the Xingu River of Brazil, a non-marine fishery, to harvest ornamental fish (Mesquita & Isaac-Nahum, 2015).

[3] In Vietnam, dive fishers may also engage in dives to 50-70m to recover metal from shipwrecks (Blatteau et al., 2015)

Labour arrangements may consist of self-employed divers who own some or most of their gear, as is the case with the fishery explored in this study (pers. obs.). Dive fisheries may operate under more questionable labour arrangements or conditions in which the violation of human rights of divers may be a concern (Ehrhardt, 2006; Eriksson et al., 2012). Describing the lobster and octopus dive fishery in Mexico, Sanchez and Paredes (2001; p.17) observed that "*In the event that the top-side assistant considers that the boat is in jeopardy, he will cut the hose of the diver and save the boat, the diver will be left to his own luck.*"

These human rights concern may draw particular attention where fisheries are strongly tied to global seafood trade arrangements such as lobster and sea cucumber (Couper et al., 2015; Ehrhardt, 2006; Eriksson & Clarke, 2015), and especially among small-scale fisheries in the developing world as they often operate in a setting where management is constrained by institutional, financial and capacity challenges making good management and enforcement difficult (Andrew et al., 2007; Salas et al., 2007). It is often in these unregulated environments that many developing-world, small-scale dive fisheries operate, in contrast with those of the developed world where diving is categorized as a commercial practice subject to labour safety regulations, including the support of modern healthcare infrastructure (e.g. Government of New Zealand, 2013).

C. Dive fisheries: physiology & health implications

This section is intended as a primer of diving physiology to provide context for dive fisheries and subsequent discussion. However, detailed treatment of this complex topic is beyond the scope of this paper (see Bennett & Elliott, 1993).

A submerged diver accumulates nitrogen in the bloodstream, the rate and extent of which are based primarily on the depth and amount of time spent underwater. The longer and/or deeper the dive the more nitrogen is accumulated, though a broad range of other factors also influence the nature nitrogen uptake (Tetzlaff & Thorsen, 2005). Under normal circumstances this nitrogen is gradually released via the lungs when the diver exhales; any residual nitrogen present at the surface is normal and is eventually released by normal breathing, unnoticed by the diver (Vann & Thalmann, 1993). Divers may conduct subsequent dives even if they are carrying residual nitrogen loads but are subject to minimum surface intervals to allow off-gassing and modified profiles for subsequent dives to maintain nitrogen accumulation within safe limits (Hempleman, 1993). Algorithms known as dive or decompression tables, originally designed from US Navy dive experiments, define safe diving limits and profiles, and form the basis of modern diving rules (Egstrom, 1993; Hempleman, 1993).

If there is saturation of nitrogen in the bloodstream and/or if there are sudden pressure changes from rapid ascents, nitrogen may come out of solution in the blood and form bubbles (Tetzlaff & Thorsen, 2005). These bubbles can travel throughout the body including (but not limited to) joints, tissues, neurological organs, heart or lungs (Levett & Millar, 2008). This may result in Decompression Illness (DCI), which encompasses Decompression Sickness (DCS) as well as associated barotraumas (Elliot & Moon, 1993a). Decompression Sickness can be classified into Type I DCS and Type II DCS (Neuman, 2002). Type I DCS symptoms generally manifest themselves in the skin and skeletal system while Type II DCS, considered far more serious, affect neurological and cardio-pulmonary systems and may also be accompanied by Type I manifestations (Elliott & Moon, 1993a; Neuman, 2002). Type II DCS classification also includes Arterial Gas Embolisms (AGE) in which bubbles are forced into the vascular system of the lungs which, if not immediately fatal, requires urgent care (Neuman, 2002).

Other barotraumas may also occur in the air spaces of the mask, ears, sinuses and gastrointestinal tracts, among others (Levett & Millar, 2008). There are also long term health consequences of repeated diving over the span of a career, even in the absence of diving accidents; these may include but are not limited to dysbaric osteonecrosis (DON; necrosis of bone from exposure to nitrogen) memory and hearing loss (Çimşit, 2001; Elliott & Moon, 1993b; Levett & Millar, 2008).

Given the possible range of diving related medical complications it is not surprising that the consequences in some fisheries have been catastrophic. The true global nature of mortality and morbidity in dive fisheries has not been evaluated. In the Nicaragua Caribbean Spiny Lobster fishery up to 3,000 primarily Miskito Indian divers operated in a fishery where divers undertook up to 12 dives per day resulting in high rates of permanent disabilities and mortalities (Barratt & van Meter, 2004; Ehrhardt, 2006). Ruffez (2008), in describing the Vietnamese holothurian dive fishery, notes a 5% mortality and morbidity rate and writes that in one province *"… half of the divers must be replaced every 10 years.*" Ruffez (2008; p. 45).

In the Grenadian dive fishery, Forman (2005) cites alarming rates of decompression injuries with 81% of divers having experienced one or multiple events of DCI. Forman (2005) also found that 41% of the individuals treated for diving injuries at the hyperbaric chamber in Barbados (period 1985-2003) from the surrounding Caribbean region were fishers. In other fisheries, however, there are virtually no diving accidents due to the characteristics of the fishery. In the Callo de Hacha (scallop) fishery in Mexico, for example, hookah divers operate at very shallow depths of 18ft/5.5m (Basurto, 2006). Interestingly, New Zealand has considered the use of compressed air technology as a potential way to mitigate fisher-shark interactions in its shellfish fishery (Government New Zealand 2013).

The reality for dive fishers is that they regularly contend with several symptoms that include, but are not limited to, joint and limb pain, chronic headaches, bleeding from nose and ears, light paralysis, partial or severe permanent paralysis and death (Barratt & Van Meter, 2004; Chin et al., 2015; Eriksson et al., 2012; Forman, 2005). Fishers have been known to describe pain and symptoms from diving injuries, and even death as routine, acceptable, or a norm for the occupation in which they engage (Eriksson et al., 2012; Forman, 2005).

Divers may choose to avoid or be unable to seek/access treatment; they may self-medicate (using analgesics) or perform risky underwater recompression procedures (to mimic hyperbaric chamber treatment) and return to diving as soon as it is feasible yet against medical advice (Eriksson et al., 2012; Forman, 2005; pers. obs.). Treatment for dive injuries depends on timely access to costly, highly specialized hyperbaric oxygen therapy (HBOT; Barratt & van Meter, 2004; Blatteau et al., 2015; Levett & Millar, 2008). Hyperbaric chamber recompression facilities may be remote, (delaying urgent treatment to minimize long-term consequences such as paralysis) or altogether non-existent (Blatteau et al., 2015; Ehrhardt, 2006; Eriksson et al., 2012; Forman, 2005). Dive fishers that operate away from the coast or in remote areas are removed from the immediate medical care required to treat diving injuries thereby compounding the risk they may take (Blatteau et al., 2015).

Beyond the immediate physiological consequences, there are real social and economic costs to individuals and communities with implications for people’s livelihoods and wellbeing. These may include loss of income coupled with the need to care for injured individuals as well as costs to healthcare infrastructure. Little has been done to evaluate this facet of dive fisheries. However, it is likely that the cost implications of dive injuries far outweigh the benefit of increased catch potential from riskier diving (Forman, 2005). These associated socio-economic costs remain largely unaddressed in dive fishing communities (Eriksson et al., 2012).

D. Dive fisheries: risk factors

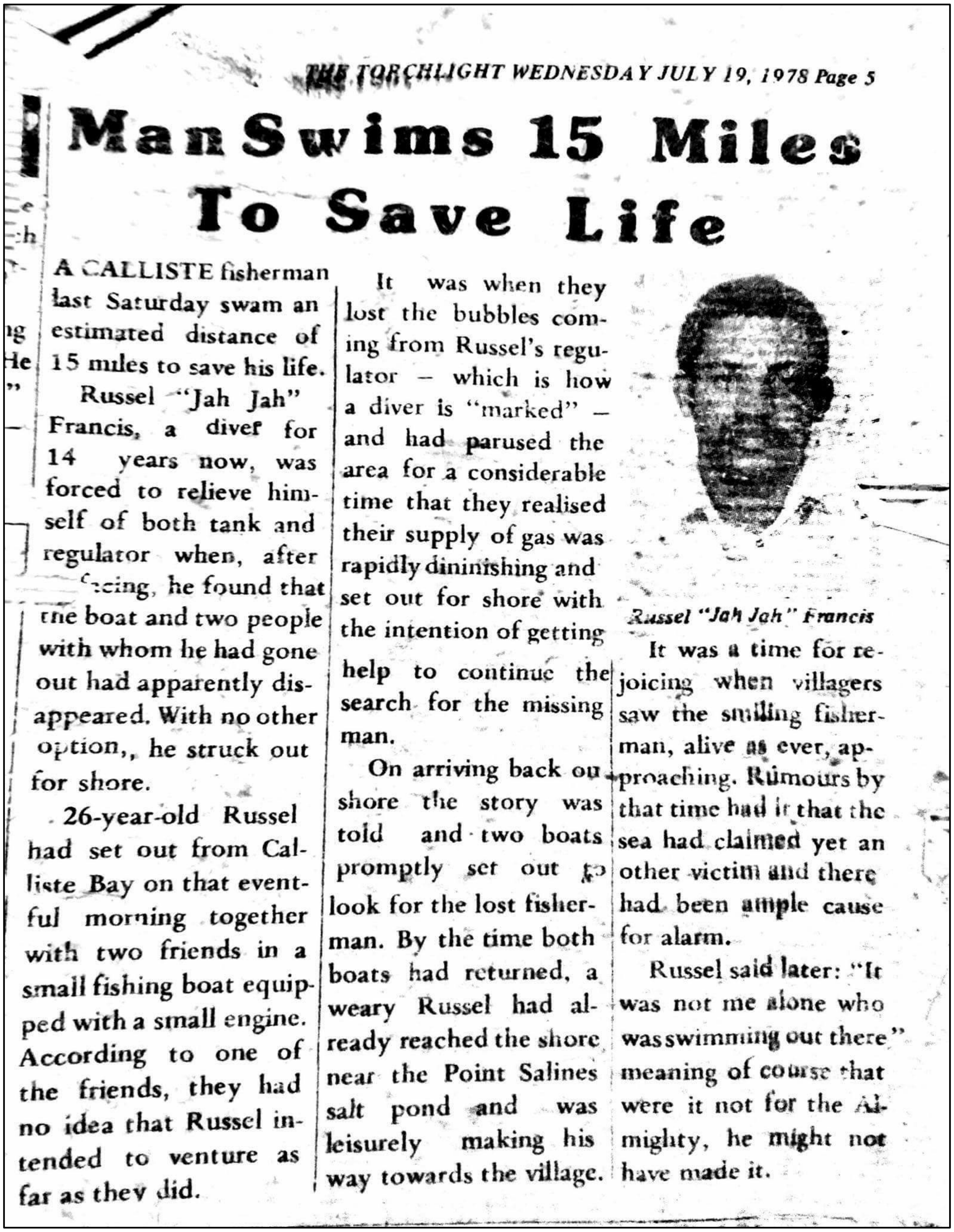
The literature on dive fisheries provides an indication of the risk factors associated with diving for marine living resources. Divers often receive little or no formal training in using compressed air technologies and learning is largely experiential (Blatteau et al., 2015; Forman, 2005; Gold et al., 2001). Poor training is a key contributor to dive fatalities in recreational fisheries (Buzzacott, 2012). The equipment used may be inadequate, such as diving without a depth/pressure gauge, or be in poor state of repair increasing the risk of equipment failure or out-of-air emergencies (pers. obs.). Compressors in hookah diving are notorious for their poor state of repair, resulting in the intake of contaminated air or compressor failures with which divers at depth must content with (Blatteau et al., 2015; Chin et al., 2015; Gold et al., 2000a; Xu et al., 2012).
Perhaps the most egregious risk factor is the repeated breaking of basic time/depth rules dictated by table algorithms that allow divers to safely dive to a particular depth for a particular duration (Barratt & van Meter, 2004; Hempleman,

1993). The constant air supply provided by hookah systems results in a near-inexhaustible supply of air, which in turn allows for very long dives. When compared to SCUBA, the probability of decompression illness is higher in hookah diving (Chin et al., 2015). Furthermore, dive fishers may exceed safe depths and times (Eriksson et al., 2012). Safe ascent rates may not be observed by divers increasing not only the risk of DCI but also AGE. This is particularly relevant for SCUBA divers running low or out of air forcing unsafe ascent rates (Buzzacott, 2012; Levett & Millar, 2008). Fishers are also likely to conduct too many repetitive dives in a single day, with surface intervals that are too short to be safe (Forman, 2005). Strenuous activity or excessive exertion, which are regular when engaging in harvesting, are factors that increase the susceptibility of DCI by driving nitrogen uptake (Tetzlaff & Throsen, 2005; Vann & Thalmann, 1993).

Buddy diving (diving in pairs for safety) is considered a fundamental rule of recreational diving, but it is not normally practiced in dive fisheries as it is likely considered inefficient from a harvesting perspective (Davis et al., 2002; Eriksson et al., 2012). This significantly reduces the ability for an individual to deal with emergency scenarios, particularly as they relate to equipment failure and out-of-air emergencies (Davis et al., 2002; Egstrom, 1993).

Becoming lost at sea is an occupational hazard of small-scale fisheries (FAO, 2007). In the Grenada dive fishery where SCUBA divers operate autonomously underwater and are tracked from the surface using only exhalation bubbles, divers face the risk of getting lost and going adrift. During the field research component for this study a fisher went missing at sea while diving[4]. The dive boat he was diving from as well as other boats spent some time looking for him. However, the search ended within a day as he was thought to have drowned. Luckily he was recovered several kilometers offshore by a passing fishing trawler after spending the night at sea. Accounts of divers being lost as a result of tracking by bubbles have also been documented in the Grenada dive fishery as far back as 1978 (Figure 4). Presumably this risk is lower in hookah fisheries where divers are connected to a surface vessel. The risks associated with chasing after dwindling resources in dive fisheries has not been explicitly examined. In other words, diving practices may become more extreme when pursuing resources that are hard to find and obtain. As sequential depletion of sea cucumbers into ever-deeper waters is known to occur, there should be a cause for concern with regards to the risk factors in associated dive fisheries (Eriksson et al., 2012, Pakoa & Betram, 2013; Toral-Granda et al., 2008). Diving deeper, as discussed above, increases the probability of diving injuries and, in all probability, the likelihood of getting lost. Equally, remoteness from medical facilities, by diving further offshore reduces one's ability to deal with emergencies.

[4] This fisher was not included in the study due to logistical constraints.



THE TORCHLIGHT WEDNESDAY JULY 19, 1978 Page 5

Man Swims 15 Miles To Save Life

A CALLISTE fisherman last Saturday swam an estimated distance of 15 miles to save his life.

Russel "Jah Jah" Francis, a diver for 14 years now, was forced to relieve himself of both tank and regulator when, after [illegible]ing, he found that the boat and two people with whom he had gone out had apparently disappeared. With no other option,, he struck out for shore.

26-year-old Russel had set out from Calliste Bay on that eventful morning together with two friends in a small fishing boat equipped with a small engine. According to one of the friends, they had no idea that Russel intended to venture as far as they did.

It was when they lost the bubbles coming from Russel's regulator – which is how a diver is "marked" – and had parused the area for a considerable time that they realised their supply of gas was rapidly dininishing and set out for shore with the intention of getting help to continue the search for the missing man.

On arriving back on shore the story was told and two boats promptly set out to look for the lost fisherman. By the time both boats had returned, a weary Russel had already reached the shore near the Point Salines salt pond and was leisurely making his way towards the village.

Russel "Jah Jah" Francis

It was a time for rejoicing when villagers saw the smiling fisherman, alive as ever, approaching. Rumours by that time had it that the sea had claimed yet another victim and there had been ample cause for alarm.

Russel said later: "It was not me alone who was swimming out there" meaning of course that were it not for the Almighty, he might not have made it.

Figure 4 Lost-at-sea incidents have long been a reality in the Grenada dive fishery. The Torchlight, 19 July 1978. Courtesy Marlon Francis.

E. Dive fisheries: ecological sustainability

Dive fisheries can be highly efficient at removing target species and can allow divers to target deeper stocks than would be feasible by freediving (Eriksson et al., 2012; Lindfield et al., 2014; Pakoa & Bertram, 2013). As no systematic review of dive fisheries exist, it is difficult to assess the state of fisheries resources that are targeted by diving or to make broad assumptions about them. However, many global fisheries stocks remain overexploited with ongoing concerns for the underestimating of fisheries catches, particularly in small-scale fisheries (Pauly & Zeller, 2016; Worm et al., 2009). Sea cucumber stocks in the Pacific and Indian Oceans, for example, have been systematically exploited, many by diving, both geographically and bathymetrically (Toral-Granda et al., 2008). In the Caribbean, Spiny Lobster and Queen Conch, subject of the fishery under study here, are considered overexploited throughout much of their range (Aranda et al., 2014; CRFM, 2011). Diving played a key role in the overfishing of the West Indian Sea Egg (*Tripneustes ventricosus*) in Grenada (Nayar et al., 2009). Since many dive fisheries occur in settings where lack of enforcement and compliance with fisheries regulations is all too common, it is reasonable to be concerned about the implications of dive harvesting on fisheries resources (Andrew et al., 2007; Salas et al., 2007).

Regulatory control measures to limit diving are generally approached from a resource conservation perspective (e.g. CRFM, 2011; Tewfik & Béné, 2004).

However, recognizing the need to manage deep-water stocks of sea cucumber concomitant with a spate of diving injuries, Fiji has considered regulating the use of compressed air fishing (Pakoa & Betram, 2013). Yet, violation of fisheries regulations is not uncommon (Erkisson et al., 2012; CRFM, 2011). In the Caribbean, for example, illegal, undersized harvesting of *P. argus* is considered one the most serious factors challenging the sustainability of stocks in the region (CRFM, 2011). Violations of resource protection regulations further compound the negative effects associated with the harvesting efficiency afforded by diving (Lindfield et al., 2014).

Other factors, such as poverty can further exacerbate fishing pressure, even when resources are severely depleted resulting in extreme negative results. While they do not specify the type of diving involved (CADF or FDF), Kinch et al. (2008) note that "Rural poverty in Papua New Guinea is causing some fishers to continue to collect sea cucumbers even when returns fall below 1 specimen per 10 hours of diving."

The description above may suggest that diving is a negative fishing method from both a human and sustainability perspectives. However, there is evidence that, when properly managed, diving can result in a sustainable fishery, and have both social and environmental benefits. Lenihan and Peterson (2004) demonstrated that diving could help protect benthic habitats of American Oysters (*Crassostrea virginica)* as opposed to more damaging traditional dredging methods. In response to increasing demand for sustainable seafood products, which command premium prices, Nova Scotia will trial a scallop-dive fishery in 2016, as an alternative to the current use of dredges (Ecology Action Centre, 2016). In the Caribbean, invasive lionfish (*Pterois spp.*) are being culled by using pole spears while diving (Albins & Hixon, 2013). Lionfish derbies (by diving), the promotion of lionfish on consumer markets and free provisioning of specialized lionfish harvesting gear to fishers are all being employed to control lionfish populations (Côté et al., 2013; pers. obs.).

Chapter 3: Methodology

The field research component of this study was conducted in Grenada, Carriacou and Petit Martinique over a six-week period during April and May of 2016. The primary research methodology for this study comprised of semi-structured interviews with dive fishers in the small-scale, multi-species Grenadian dive fishery. These interviews were supplemented with desktop research to review the dive fisheries, small-scale fisheries and hyperbaric medical literature. Direct and participatory observations also form part of the field research for this study. A qualitative approach was chosen to gain an understanding of context, behaviors and connections that lead to unsafe dive profiles often missing in other studies of dive fisheries (Bradely et al., 2007).

A. Dive fishery interviews

Given the anticipated engagement of human subjects for this research, an application for review by Dalhousie University's Research Ethics Board (REB) was submitted. The REB assigned the approved *Project Number 2016-3814* to this study. The approved study proposal was forwarded to the Fisheries Division of the Ministry of Agriculture, Lands, Forestry, Fisheries & Environment of the Government of Grenada ahead of the researcher travelling to the study location. Discussions with the Chief Fisheries Officer (CFO) and Deputy CFO followed, after which the researcher sought the assistance of District Extension Officers to recruit dive fishers for the study. In some districts, dive fishers were recruited directly by the researcher following discussions with relevant District Officers.

Interviews with divers were conducted across six dive fishing communities in Grenada, including the sister islands of Carriacou and Petit Martinique (Figure 1). Divers from the following communities were recruited into the study: Calliste, Woburn, Grenville, Sauteurs, Hillsborough (Carriacou) and Petit Martinique (Table 2).

Table 2 Number of divers interviewed, by community.

Community	Parish	No. of Interviews
Calliste / True Blue	St. George	11
Woburn	St. George	3
Grenville	St. Andrew	4
Sauteurs	St. Patrick	4
Hillsborough	Carriacou	3
Petit Martinique	Petit Martinique	5
	Total:	30

Approximately one third of the diving population was interviewed for this study (30 participants) at landing sites or in their home communities. No official figures for the number of dive fishers in Grenada were available at the time of writing. However, Forman (2005) interviewed most of the divers (85) in Grenada, Carriacou and Petit Martinique. From discussion with fishers, this figure appears to have remained relatively stable. In order to qualify for the study, participants had to be 18 years or older, and self-identify diving as their primary means of livelihood. This included dive fishers (active or retired), boat crew, and inactive divers who have ceased diving due to injury (but were not ambulatory). Although crewmembers qualified for selection, none participated in the study.

The researcher engaged dive fishers informally prior to requesting interviews, which were conducted with the prerequisite that informed oral consent be given by participants. Additionally, participants were given the choice to have their responses recorded using a digital audio recorder. A total of 19 respondents agreed to have their responses recorded. Responses for six participants were not audio recorded as the researcher felt that they would be more at ease or conditions were not conducive for recording (e.g. windy conditions). The semi-structured interviews were qualitative in nature and ranged from 17 - 90 minutes (38 minutes average). Semi-structured interviews allowed the researcher to engage in a discussion with fishers, avoiding the rigidity that may be associated with a fixed set or order of questions. Where appropriate, questions were adapted to the participants and direction of the discussion resulting from the interview. Furthermore, not all questions were necessarily equally relevant to all respondents, for example, questions concerning long-term changes to the fishery were more suited to older and experienced divers. Two respondents were excluded from the analysis as it became evident that they did not engage in dive fishing as a primary means of livelihood.

B. Direct and participant observations

This study incorporated an ethnographic approach so that the collected data could be placed into an appropriate cultural context (in this case the culture of diving in the fishery) and to gain a deeper understanding of the dive fishery not afforded by relying solely on interview questions (Russell, 2006).

The researcher also undertook direct and participant observation of fishing activities. The researcher's role as a researcher was declared and the intent to recruit interview participants was disclosed to fishers from first meetings with individuals. This method consisted solely of observing fishers preparing to head to sea or observing the landing and cleaning of catch. The researcher assisted some fishers in loading and unloading during initial engagement with fishers, where appropriate, to build rapport.

The researcher also participated in two separate dive trips, one for lobster and one for conch, conducting three dives per trip. The intent was to participate first hand in the diving and fishing practices as well as build additional rapport with fishers (Kawulich, 2005). These observations, combined with fishers' own description of daily diving and fishing activities during interviews form the basis of the ethnographic account of the Grenadian dive fishery of Chapter 4.

This research benefited from participant observation in a number of ways. Russell (2006) identifies five reasons for its application in field work, including providing the researcher with an intuitive understanding of dive fishers' practices and concerns; greater context and validity in interpreting responses from interviews in data analysis, and reduced reactivity from face-to-face interviews.

Given the paucity of ethnographic descriptions of dive fisheries in the literature, the research questions addressed in this study was enriched and contextualized through these observational approaches. The ethnographic account of the Callo de Hacha dive fishery in the Seri Territory of Mexico by Basurto (2006) is a rare exception that provides context of the practices fishers undertake.

C. Analytical framework and data analysis

The framework that informs the primary research question is the rights-based approach (Figure 5) proposed by Allison et al. (2012). While this study does not directly address the primary, though valuable, human rights discourse proposed by Allison et al. (2012), it is informed by two other arguments put forward in their paper. Firstly, it is informed by the relationship between fishers' vulnerability and their ability to be resource stewards. Secondly, this study took into account that factors influencing a fishery may lay both within a fishery (e.g. fisheries size catch regulations) or outside of it (e.g. access to health services). Identifying where these vulnerabilities are found has consequences for identifying how they may drive unsafe dive profiles and what management approaches are suitable to addressing them.

These arguments are relevant for dive fisheries, particularly in understanding why fishers engage in the type of diving they undertake. Firstly, it considers whether fishers who risk their lives for livelihoods are concerned with or in a position to partake in the management of the resources they target. This frames the discourse of unsafe dive profiles in the context of why fishers would be active resource stewards in a fishery where taking life and death risks clearly takes precedence. Secondly, in seeking to elucidate the underlying drivers of unsafe dive profiles, the research was not constrained by assuming that these were to be found only within the dive fishery, but may also be influenced by external forces. While exploring all facets of the framework (Figure 5) was beyond the scope of this study, it provided a useful way with which to contextualize the small-scale dive fishery system, inform the analysis and management recommendations.

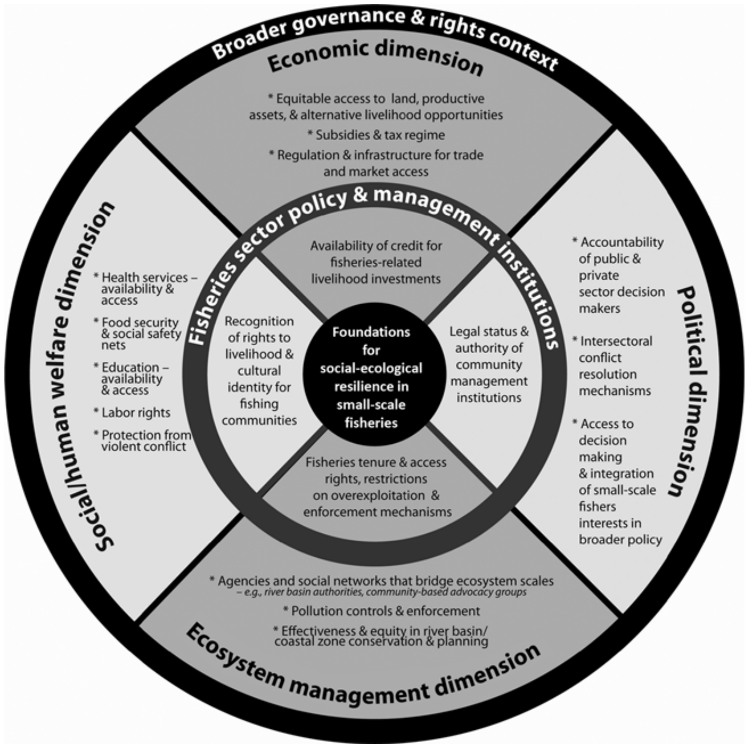


Figure 5 Rights-based framework (reproduced from Allison et al., 2012; p.22)

The list of questions used to guide the researcher's interviews with participants formed the initial template for the data analysis. The interviews with participants were semi-structured and resulted in open-ended discussions that were driven by the participants but guided by the researcher. As a result, the order of responses varied significantly and divers often offered answers to questions before they were posed. Similarly, not all participants were asked or answered all the questions as experience and position within the fishing community was not uniform for all respondents (e.g. older divers were better placed to provide historical context for the fishery or traditional methods of diving).

An integrated approach to thematic development using both a deductive framework or starting list (interview questions) and an inductive review of codes based on grounded theory was applied to the analysis (Bradley et al., 2007; Russell, 2006). The primary interview data from the recorded (audio and written) interviews was tabulated into an Excel spreadsheet using the initial set of interview question as a template. Each data column headings corresponded to a question in the interview (starting list). As data entry proceeded, original data column headings were either combined or further differentiated. Ultimately these were grouped, to reflect the emerging themes and connections from the responses. These grouped headings resulted in the themes presented in Chapter 5. This process was in part informed by the researcher's direct and participant observation of the fishery. The rights-based framework also informed the analysis as it sought to identify where vulnerabilities that had an influence on fishers could be found.

Chapter 4: Grenada's Dive Fishery & Practices

A. Overview

What follows is an account of Grenada's dive fishery based on interviews conducted for this study and on the researcher's, direct and participatory observations of the fishery.[5] There is no published record describing Grenada's dive fishery, and as such this chapter may be unique in providing some ethnographic context for this practice. While this account fills a gap in recorded knowledge of the dive fisheries, it must be noted that it is based on a period of short field research (six weeks) and on two dive trips by the researcher. More extensive field research would no doubt allow for a more comprehensive ethnographic description.

The Grenadian dive fishery is conducted exclusively by Self Contained Underwater Breathing Apparatus (SCUBA) diving. It operates as an open-access fishery across Grenada, Carriacou and Petit Martinique, from several communities (Figure 1) and primarily targets Caribbean Spiny Lobster (*Panulirus argus*) and Queen Conch or *Lambie* (*Lobatus gigas*). The macroalgae *Gracilaria spp*. (also known as *seamoss*) which was historically gleaned by hand from intertidal areas is now occasionally harvested by diving (Mohammed & Lindop, 2015; Smith et al., 1984).

[5] Note: this discussion does not follow fishers outside their primary fishing activities and may well omit important information relevant to understanding the dive fishery.

Divers may target some species opportunistically, meaning that the species are not the primary intended catch but are harvested if encountered. Sea turtles, pelagic and reef fish are common examples of opportunistic target species but they may also form intended catch for some individuals. Fish, for example, becomes a primary catch species for some divers when the lobster season is closed[6].

The precise moment when SCUBA diving was introduced to the fishery is not entirely clear and little is known about the early history of diving in the fishery in Grenada. It likely began in the late 1960's or early 1970s and pre-dates the tourism dive sector. Multiple respondents identified an individual named Dennis Ross based in the capital, St. George's, and who worked with an American identified only as "Clancy" who introduced the practice and found markets for lobster and conch in the United States. Another American individual supported the dive infrastructure supplying compressors and dive equipment for some time following the US invasion of Grenada in 1983. The community of Calliste would have been the first fishing community to take up SCUBA diving whose fishers are known for diving throughout the tri-island state.

Today, fishers use either uncovered, undecked cigarette or fiberglass boats with single outboard engines (Figure 6). Cigarette boats are locally built, framed wooden boats that may be partly fiber glassed for additional durability and range

[6] May 1st – August 31st (CRFM, 2011)

from 16ft/5.4m to 20ft/6m in length. Pirogues are larger boats made of fiberglass, generally procured from Trinidad and can reach 26ft/8m in length. Engines are two-stroke outboard gasoline engines that vary widely in size from 40HP to 200HP though small to mid-sized engines are more typical.

Figure 6 Typical fiberglass pirogues (left and center) and cigarette boats used in the Grenadian dive fishery. Photo by author.

Crew arrangements consist of one boat captain known as the *keep up man* who is responsible for driving the boat and keeping up with (following) the diver's bubbles on the surface. This is the primary means by which boat captains track their divers. Typically there is one diver per boat though this arrangement is not inflexible and having two divers on a boat is not uncommon.

B. Typical diving day

A typical diving day begins with early morning preparations with some divers or crew arriving at shore as early as 0600 with most boats heading out to sea by 0800. Boats are either anchored or moored at the bow and have a stern line tied to the shore. In some cases, the entire boat may be manually hauled out onto shore, particularly if they are in exposed coastal locations.

Daily preparations involve the loading of fuel, dive cylinders, dive equipment, drinking water and personal items. Fishers travel to shore either on foot or by car. Some will travel with the trucks or vehicles transporting filled air tanks and fuel to the boats. Some fishers may spend time socializing, discussing sea state or the previous day's activity as well as deciding where to fish that particular day before heading out to sea. This may occur among fishers from a single boat or among multiple boat crews, particularly if they decided to travel together or *in company*. Travelling *in company* is an arrangement that allows fishers to cooperate in case of emergencies (e.g. engine failure, lost-at-sea diver, dive accident) and traditionally also resulted in sharing of dive sites on which to fish.

Cylinders are typically filled offsite and need to be transported, along with fuel, to where boats are located. Once loaded, boats will head out to various sites to dive for the target species of choice. The decision on where to fish, what to fish and whether to fish with other boats is based on a wide range of factors that may include but are not limited to weather/sea state, success at previous site, time of season, crew arrangements, social arrangements, state of market, pre-existing purchasing arrangements or demand for product. Sites are commonly located using shore-based landmark features (e.g. houses, hills, etc.) although handheld Global Positioning System (GPS) units are also used.

Typically divers will conduct four dives of varying durations to varying depths (usually in the range of 80ft/24m to 120ft/36m, though there is significant variance in this range). The duration of each dive is highly variable and depends largely on depth, air consumption rates and the effort exerted underwater but typically range from 20-40mins. The duration of surface intervals between dives is largely dictated by time spent moving to a new site, adjusting/preparing equipment for the next dive or sorting/processing catch. Brief bounce dives or aborted attempts (e.g. less than 5 mins to 80ft/24m) in search of catch are not uncommon and occur when fishers do not find what they are looking for.

The diving equipment used in the fishery is modified from recreational SCUBA equipment described above (Figure 2). Most fishers generally forego a BCD as it is considered too bulky and cumbersome for fishing underwater. Although some see value in having a BCD as a floatation device if one is lost at sea or for increasing the chances that a dead diver can be recovered. Instead, divers use a simple backpack-styled harness with no buoyancy control. Regulators are mostly stripped down to include only one second-stage mouthpiece from which to breathe and a simple pressure gauge. A secondary, back-up second-stage is considered hazardous as it may get caught on the reef and is kept as a spare part for repairs. Variations on the theme exist with some divers diving without gauges (though this is a largely outdated practice) and some divers wearing BCDs or using a secondary second-stage mouthpiece. Thermal protection is not a safety concern at this latitude. Some divers wear thin wetsuits (typically 3mm) while others wear t-shirt or long sleeved shirts for protection from contact with the benthos and the catch they handle. Additionally, fins and masks are standard equipment. A diver will typically carry a spear gun allowing for the opportunity to shoot fish when encountered.

Boats will return to shore around noon and the afternoon is dedicated to processing and selling catch. Catch is typically cleaned and parceled between crewmembers. It is then brought to buyers with whom divers have a prior arrangement or, where no such arrangement exists, buyers must be sought out. Transportation arrangements at the end of the day are typically the same as those in the morning as empty tanks and fuel cans must be hauled away to be refilled.

C. Air supply

Dive tanks are filled using air compressors. There are currently eight suppliers of compressed air throughout Grenada, Carriacou and Petit Martinique. Five of these are operated by private individuals whose target market is dive fishers, while the remaining are recreational dive operators. Independently run compressor air fill stations are located in Frequente, on the Maurice Bishop Memorial Highway[7], Grenville, Petit Martinique with a compressor coming on-stream near the fish market at Sauteurs during the field phase of this study (Figure 7). Where divers fill their tanks is not necessarily based on proximity to a filling station. Air quality at some fill station is a concern for divers and they prefer to fill their tanks elsewhere despite higher transport costs. Existing relationships between actors in the fishery, which may also dictate where they decide to fill their tanks. Divers in Grenville and Sauteurs transport their tanks to the south of the island for filling, though the new compressor at Sauteurs may change this dynamic. Additionally, at least three recreational dive operators in the tourism sector also fill tanks, though this situation tends to be fluid and arrangements a made on a case-by-case basis. Some dive operators will only rent tanks to divers that are holders of valid dive certifications (e.g. former PADI[8] Divemasters) or on the condition that divers agree not to violate local fisheries regulation or catch endangered species such as sea turtles. Such arrangements are difficult to enforce and are largely based on mutual trust.

[7] Not shown on map. Both compressors are in close proximity to Calliste.
[8] Professional Association of Diving Instructors

Figure 7 Air compressor recently installed at Sauteurs. Photo by Simone Kist, with permission.

Dive compressors in Grenada are not actively regulated or monitored, although a permit to operate “a SCUBA tank filling facility” is required under the Fisheries (Ammended) Regulations SRO.24 23(1) (1996). The maintenance of equipment and the quality control of filled air is the responsibility of the compressor owner/operator. The relative quality of air fills from different suppliers is a concern for a number of respondents interviewed. Based on other dive fisheries, air quality poses a genuine risk to diver health (Chin et al., 2015). While it is certainly a safety factor to consider in Grenada’s dive fishery, specifically testing the air supplied by compressor facilities would be the only way to objectively determine whether there is an issue of air quality supplied to divers. Ironically, while recreational dive operators are often reluctant to fill tanks for divers knowing the type of dive profiles they undertake, they likely remain the most reliable source of clean air on the island.

While the economic benefits to compressor operators have not been assessed, they likely provide valuable livelihood opportunities given their abundance and continuous operation. Most divers do not own the dive cylinders (tanks) and rent them from air fill stations. Divers must pay for air fills (EC$12/US$4.44 per tank[9]), additionally divers also pay for transportation of tanks from the air fill station to where boats are kept if they cannot transport the tanks themselves (Figure 8). This cost of transportation will vary based on distance, fishers in Grenville and Sauteurs usually transport tanks in bulk once per week to reduce cost.

[9] 1 USD = 2.70 XCD which is permanently pegged to the USD

Figure 8 Full SCUBA cylinders awaiting collection by divers at the Grenville Fish Market. Photo by author.

D. Lobster diving

Lobster is harvested using metal nooses attached to wooden sticks (approx. 3ft/1m long). Typically, the circular noose is slipped in behind the tail of the lobster and brought to where it meets the thorax and tightened using a quick jerk of the stick to secure the lobster. Lobster that are tightly bunched with others in dens or not easily accessible are coaxed or prodded out using another, larger stick. Alternatively, particularly for larger individuals, the noose may be placed over and at the base of the lobster's antennae. Divers carry approximately two-dozen nooses, securing the sticks under the straps of a cylinder harness or BCD, if used. They will also carry a spear gun for opportunistic fish catches. As lobsters are caught the sticks may be bunched and tied together with a piece of rope and left on the seafloor to be retrieved before surfacing while the diver continues to harvest other lobsters nearby (Figure 9).

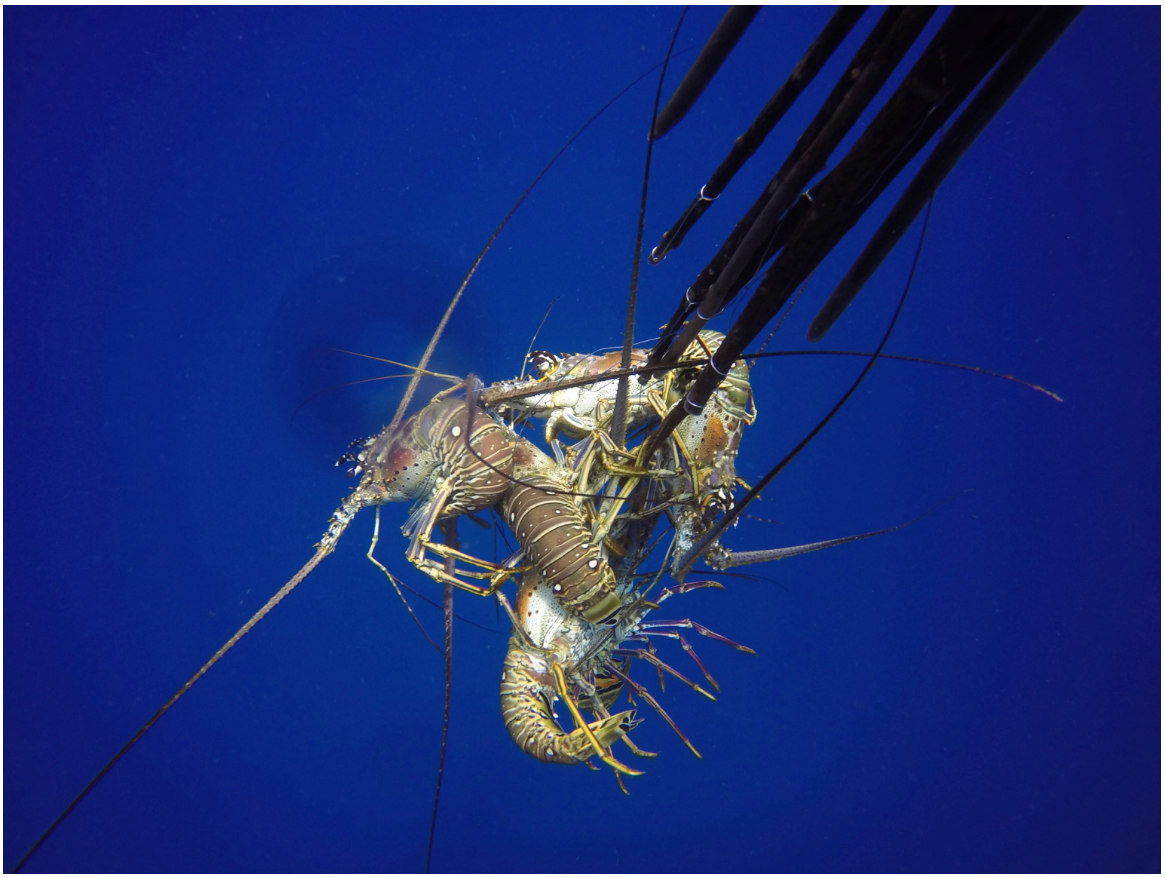


Figure 9 Lobsters bunched together on nooses being carried to the surface. Photo by author.

Markers, consisting of a weighted line tied to a buoy may be employed to mark areas where the diver may wish to return for a subsequent dive, either the same day or on another occasion. This marker is deployed by the *keep up man* at the request of the diver on surfacing and is a quick affair in order to secure the location before currents cause the diver and boat to drift away from the site. Once the buoy marks the site, landmarks on shore or handheld GPS are used to identify the location for subsequent visits; the buoy is then retrieved.

Lobster are either sold whole or tailed (the tail removed from the head and thorax of the animal). Lobster heads are either thrown at sea or given away and are typically used as a filler and flavoring agent in fish or seafood broths locally known as *waters*.

E. Conch diving

Diving for conch is a more equipment intensive process than diving for lobster. Conch is harvested underwater by hand and placed in a basket hanging by a rope from the boat (Figures 2; 10). The basket, made from chain-link fence is weighted with a heavy stone and may have a deflated fender attached to it. As the basket is filled with conch, the diver(s) periodically adds air to the fender through a small hole cut for that purpose at the base of the fender. This ensures that the fender is nearly full of air by the end of the dive. The fender acts as a lift bag increasing the positive buoyancy characteristics of the basket, though while it does not float the catch to the surface it reduces the effort of hauling the basket to the boat at the end of the dive. During the dive, the basket hangs freely from the boat, which is not anchored. The keep up man maneuvers the boat and the basket by following the divers' bubbles at the surface. As a result, the basket moves around and will change depths depending on the height of the waves and movement of the boat at the surface. This motion, when combined with prevailing underwater currents and the movement of divers at depth, can result in a haphazard movement of the basket underwater. Divers collect multiple conchs in each hand, readily up to eight animals, and then seek out the basket in which to deposit the conch. This requires effort to swim to and at times, ascend up to the basket. When heavy, the basket may bounce off the seafloor as the boat moves around.

Figure 10 Chain-link fence basket used to harvest conch, with a fender typically used to increase buoyancy of the basket. Photo by author.

When the basket is full the divers head to the surface and if necessary will also hold additional conch in their hands. Once back on the boat the *keep up man* and diver(s) haul up the heavy basket to the side of the boat together. The rope is hauled over the side of the boat, which is protected from wear, by a section of PVC pipe cut and attached to the leading edge of the side of the boat over which the rope is pulled. A pin made of construction steel rebar (approximately 6in/15cm long) protrudes out this portion of the side of the boat and is used to tether the basket to the side of the boat as it is too heavy to haul over the side and into the boat when full.

The animals are then taken out of the basket one by one and the animals in the shell is removed. This is done by breaking a hole in the apex of the shell using a hammer and cutting the animal out with a knife, work that is typically shared by all members on the vessel.

A daily routine for most fishers in the Grenada dive fishery consists of an intense period of diving in the first half of the day with only short intervals between dives. Fishers harvest conch by hand and lobster using nooses through labor-intensive methods at varying depths. Once catch has been harvested and processed, priority is given to selling the catch during the second half of the day. This account of the fishery shows established practices and norms that fishers follow in their quest for livelihoods from diving.

Chapter 5: Results and Discussion

This chapter presents and discusses the results derived from interviews with dive fishers and is divided into two parts. The first part introduces the themes identified from the analysis, elaborating on each in turn. The second part identifies and discusses the drivers that result in the dive practices that occur in the Grenadian dive fishery.

A. Thematic breakdown of interview responses

a. Themes - Overview

The identification of the six themes described below were identified by the analysis of the interview data, supported by direct and participant observation and informed by the rights-based framework (Chapter 3).

Dive History: This theme is primarily concerned with individual dive fishers' dive history, why they entered the fishery and how they learned to dive. It also includes broader perspectives on the emergence of the dive fishery in Grenada.

Dive Practices: The knowledge and experiences fishers derive from diving and how it informs their view of the practice of diving is the common thread in this theme. Furthermore, it describes the current practices used by fishers including the gear they use and the infrastructure that supports the fishery.

Risk Perception: This theme deals exclusively with the idea of risk perception from fishers point of view by identifying the factors that fishers consider as risk drivers in the fishery as well as their personal experiences with diving related incidents and injuries.

Dive Safety: Here, the factors that fishers consider to be beneficial to improving safety are identified. Issues considered in this theme also take into account the changes in fishing practices that fishers may have undertaken over their career (i.e. modification behavior to reduce diving related risks). Factors that may be relevant to improving dive safety are also included.

Ecosystem Sustainability: In this theme, fishers' knowledge and perception the state of the resources they target is examined. In addition, it provides a qualitative examination of the responses from fishers relating to temporal (inter- and intra-seasonal), catch size, geographic and bathymetric variations in catches.

Socio-economic Dimension: The socio-economic aspects of the fishery are grouped into this theme and deal with the concerns fishers have regarding their ability and methods of securing buyers to sell their catch to. It also examines the socio-economic potential of self-organization as identified by fishers in interviews.

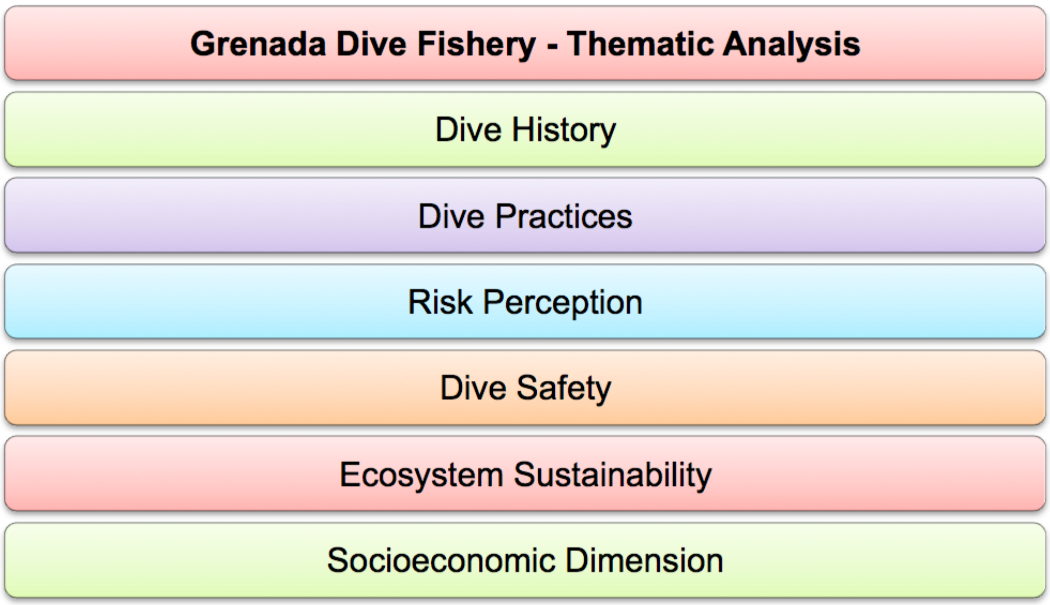


Figure 11 Thematic breakdown of interview responses

b. Themes – Interview Results

This section will analyze data from the interviews, organized per the themes defined above. This analysis is supported and contextualized by direct and participant observations made by the researcher. Due to the interconnected nature of fishers within and among different dive fishing communities, direct quotes from respondents are deliberately excluded in the discussion to safeguard their privacy. The size of the sample (30 interviews) and broad uniformity in the practices recorded in the dive fishery means that the data presented here largely reflects responses provided by multiple respondents. This approach also minimizes the risk of identifying individual fishers. At the end of the chapter this data is will be placed into context, following the analytical framework described in Section 3.C (Figure 5).

I. Dive History

The Grenada CADF evolved from a freedive fishery. Prior to the introduction of SCUBA, fishers harvested lobster, conch, fish, algae and turtles by diving *barewind* (freediving). With rare exceptions, the majority fishers begin their diving careers as freedivers with SCUBA diving being introduced through acquaintances or family members involved in the dive fishery. Some individuals, particularly those making career changes from other sectors such as construction or tourism, may forgo a pre-freediving fishing phase entering directly as new divers. However, most have been exposed to fishing or freediving in some form even if they were not full time fishers prior to taking up diving.

Training involves the transfer of the most basic knowledge required to become a diver. It involves informal mentorship from an experienced diver with the most effort concerted on how to breathe properly underwater and equalizing ear spaces. New divers are generally warned on the risks of diving, and told of practices that might mitigate accidents such as not coming up too fast, time between dives and *not blowing tanks* (exhausting air supply at depth) to allow enough air to make it back to the surface. Some respondents are self-taught divers based on observing other divers in the fishery and subsequently acquiring their own gear, although their first ventures out to sea are usually with an experience crew. Some divers begin as *keep up men* and move onto diving. Three respondents gained their PADI Divemaster certifications as employees in the dive recreational dive tourism sector, allowing them to be responsible for divers as they guided tourisms underwater, but their first SCUBA experiences were in the fishing sector. The transition from fishing to recreational diving is not necessarily linear with some fishers having shifted between the two more than once.

It is not uncommon for divers to begin at a young age, dropping out of secondary education to begin a fishing career. The average age of active divers interviewed was 49.4 years. Divers have been diving an average of 18.8 years. These figures do not include the two retired divers (65 and 70 years of age) who averaged 21.5 years of diving between them before they stopped diving. All respondents were male. No female divers were found to be active in the fishery although some, from dive fishing families, work in the recreational tourism dive sector.

II. Dive Practices

Typically, divers will undertake four divers per trip but this number can vary between two and five dives. Divers only undertake one trip per day. These dives are undertaken within a four – six-hour period that includes travel to and from sites and surface intervals. Monday to Friday working weeks are standard for most divers, but six-day working weeks are not uncommon during the lobster season.

As illustrated in Chapter 4, diving depths vary greatly but give some indication of the type of diving they under take. However, this does not provide valuable profile information that can be subject to statistical analysis, such as depth changes during the dive or ascent rates that may provide a better sense of how divers actually dive (Huchim-Lara et al., 2015).

Fishers are recognized as exceptional knowledge holders of the resources they target (Johannes et al., 2000). Similarly, Grenadian divers hold a vast amount of dive (and fishing) knowledge and experience. Established and experienced divers are a valuable source of knowledge for new entrants into the dive fishery. However, the advice of experienced divers is not always accepted, particularly where it concerns behaviors that may lead to DCS. Therefore, experiential learning remains an important element for new divers. Experienced divers may be divers who have gained seniority through time spent diving, but those who have worked in the recreational dive tourism sector are also important sources of knowledge. In addition to maintaining a relationship with those that remain in the tourism dive sector, they are also able to transmit resources such as recreational dive manuals, which are shared within the fishing community. The Internet, for those with access to it, also provides an important resource for learning about diving.

The caveat is that highly technical dive knowledge is often misunderstood or misinterpreted. This is not to say that fishers are unable to understand this information, rather misconceptions may go uncorrected or beliefs about certain practices become norms. As one respondent highlighted, there may be no one who has mastered the information to be in a position to correct misunderstandings gleaned from dive manuals. Furthermore, some divers believe there is a pill that can cure DCI or would like to see one developed which underscores the lack of understanding of the fundamental principles of dive physiology.

III. Risk Perception

In their responses, dive fishers recognize two types of diving injuries, *bubbles* and the *bends*. There is no precise set of symptoms that divers identify as fitting these two categories. However, divers with *bubbles* are likely suffering from mild symptoms of decompression sickness (DCS) and divers with the *bends* are suffering from the more severe DCS symptoms or DCI. These findings are consistent with Forman (2005) who classified *bubbles* as Type I DCS and the *bends* as Type II DCS with AGE.

Seventy-six percent of the divers surveyed consider the practice dangerous or very dangerous. Divers are well aware of the consequence of diving: 82% of the respondents reported having experienced DCS one or more times. They continue to dive despite these experiences even if left with permanent disabilities. Virtually all divers have witnessed other divers being injured. This reflects Forman's (2005) results where 81% of divers reported having suffered one or multiple incidents of DCS over their careers. Forman (2005) cited at least on case of suspected Type II DCS with AGE occurring during the course of his study. Accurately attributing cause of death can be difficult as there maybe multiple contributing factors to a dive accident. An out-of-air emergency, for example, may result in a drowning secondary to an air embolism due to a rapid ascent (Buzzacott, 2012).

Despite the perception of danger and awareness of the consequences, divers continue to fish using SCUBA. Fishers consider this risk from different perspectives. The risk may be conditional and subject to behavior modifications, it may be an accepted element of occupational satisfaction or may be accepted as a necessity associated with diving for a living.

Divers consider diving as dangerous but condition their statement by saying that they take the necessary precautions while diving to mitigate the risk, though what those precautions are is not always not evident (e.g. performing a slower accent occasionally). Often, fishers consider the risks of diving worth the rewards reaped from fishing. Fishers consider the ability to make quick decisions underwater an important element to mitigating the risks associated with diving, a skill learned through experience. Fishers recognize the increasing danger associated with the increasing depth of diving. Lobster diving, for example, is considered almost universally more dangerous for this very reason as it is not unusual to find lobster in deep water.

Diving is considered a desirable activity associated with a certain love for diving and the sea that divers cite as important to them. A desire to be at sea, a sense of happiness when they are on or under water was expressed by a number of respondents. Others recognize diving (and fishing) as a positive attribute, and to be an activity through which they gain experience and learn about their environment. Many fishers also embrace the ability to work for themselves.

Importantly, there is livelihood element associated with diving, which may take different forms. Divers consider the money earned from diving to be favorable, particularly when compared to other occupations. Respondents that have previously worked in the tourism dive industry consider the monetary rewards far superior than working as Divemasters. This is perceived to be especially true when the number of hours worked between diving for fish versus diving for tourism is compared. One key caveat that former Divemasters on fix salaries point out is that earnings from dive fishing, while considered more favorable, are less stable as they are prone to vagaries in catch. One corollary benefit of diving as a Divemaster is the reduced occupational risk of dive injuries.

Irrespective of whether they view diving as a positive activity, many consider diving to be their only livelihood option, citing that there is a lack of suitable alternatives. In which case diving is seen as a necessary risk they must face in order to earn a livelihood. This may have perverse consequences where divers that have been left with permanent disabilities are then precluded from certain other livelihood alternatives such as construction (e.g. inability to perform certain construction work due to unsteady gait). This ultimately extends their diving careers and increases probability of getting subsequent decompression injury (Forman, 2005).

There is also a certain degree of fatalism associated with diving. Many divers believe that there is no safe way to dive for a livelihood in fisheries. Conversely, experiencing DCI is a strong modifier of behavior for divers. How this modifier is manifested in actual practice, and for how long, is difficult to determine but it factors in interview responses from divers. Modified behavior includes 'taking more precautions' and while rarely elaborated on, might include making fewer divers (four per day instead of five) or diving shallower depths. Older divers surveyed once regularly dove to 42m/140ft reflected that such depths are too far dangerous and would not repeat such feats today as new dive fishers.

IV. Dive Safety

i. Hyperbaric chamber facility

There is currently no facility on the island that provides HBOT in Grenada. Anecdotal reports of attempts to establish a hyperbaric chamber over the years have existed but could not be verified for this study. Recent efforts spearheaded by actors in the recreational tourism and private healthcare sectors to establish a hyperbaric facility on the island foundered when the supplier and the selected chamber failed to materialize for reasons not entirely evident (pers. comm. Phil Saye; Christie Finney). Significant planning including training of medical personnel, shipping arrangement and construction of basic physical infrastructure to receive the chamber had already been put in place. During recent meetings with fishers and government officials it was made known that the National Insurance Scheme (NIS), the national social security agency, would be a benefit provider to for hyperbaric treatment to fishers registered with NIS (NIS, n.d.; pers. comm. Phil Saye). During discussions with fisheries officials and subsequent interviews with fishers for this research it became evident that neither were yet aware that the efforts to establish a chamber facility were experiencing severe difficulty. This situation is fluid and may yet change.

The hyperbaric chamber at the Barbados Defense Force Headquarters has for many decades been the only facility available to the region and has been operational 24/7 since its inception (pers comm. Dr. Michael Brown). Fishers from the region, including Grenada, have relied on this facility for treatment (Forman, 2005). According to respondents, arrangements to an off island chamber usually take at least a day or more to arrange. The benefits of a hyperbaric facility for the recreational dive sector is evident and would provide much closer critical care for injured dive fishers. Hyperbaric chambers are also used to treat other medical conditions such as burns and wounds and would serve to augment existing medical infrastructure on the island (Kindwall, 1993).

However, there may be unintended consequences with the presence of a hyperbaric chamber on the island. Forman (2005) cited the possibility of increased risk taking by fishers if they knew there was a facility nearby that could treat them. Interview responses certainly support that argument as divers overwhelmingly identified the presence of a hyperbaric chamber on the island as a way to improve dive safety. The absence of a hyperbaric facility also clearly frustrates fishers as they generally cannot afford to access the facility in Barbados, even if they are able to, as significant delays are involved reducing the efficacy of treatment and chances of a full recovery (Forman, 2005; Levett & Millar, 2008). The provision of HBOT does not improve dive safety but is used to treat and mitigate the consequences of DCI (Levett & Millar, 2008).

ii. Lost at sea incidents

As described above, divers are tracked using bubbles in the Grenadian dive fishery (Figure 4). The keep up man on the boat is responsible for visually tracking the bubbles of air that divers exhale and ensure the boat stays close to the divers. Tracking a diver's bubbles from a boat takes significant skill and experience. Bubbles tend to diffuse into smaller ones as they ascend and interact with current and surface waves. Tracking multiple divers that are moving in different directions further compounds this risk. The use of surface markers (a float tied by a line to the diver), a common feature for keeping track of divers in recreational diving (pers. obs.) is rarely used in the dive fishery. Divers cite the pull of the float from the surface as limiting their ability to move freely underwater.

Thus, getting lost at sea is a significant occupational hazard. The vast majority of the dive fishery occurs offshore (up to 15mi/24km for divers in Calliste and Woburn) or among the smaller outlying islands, virtually all of it in waters with strong and changing currents (referred to as *tides* by divers). Some divers find the thought of getting lost at sea, particularly the prospect of their bodies not being recovered for families to bury, far more troubling that the risk of DCS.

Divers fortunate enough to be recovered will spend hours, sometimes days at sea before being rescued. Infrastructure for rescue, particularly when several kilometers offshore, is generally limited and will largely rely on other fishing boats to join the search. Such efforts are costly ventures and can run into the thousands of dollars in fuel cost before lost fishing time and revenue is even taken into account.

V. Ecosystem Sustainability

The introduction of SCUBA to the Grenadian lobster and conch fishery has allowed fishers to remain under water longer and venture deeper waters than possible by freediving. Responses from divers indicate a recognition of possible inter- and intra-seasonal depletion of the fishery resource. Experienced divers and older respondents recall a time when everything was caught by barewind diving, in some cases within swimming distances of the shore. Among these divers, there is a consensus of the need to venture much further out to sea to find lobster and conch than when they first started diving. Even seamoss, which used to be gleaned from or near the shore, now needs to be harvested by diving. Divers in the south of the island now frequent fishing shoals several kilometers offshore while divers from Grenville are known to make longer trips as far as the sister island of Carriacou when catches around Grenville become uneconomical.

In interviews, fishers report seasonal changes in the lobster fishery where they harvest lobsters in near-shore waters at the beginning of the season and move further out as the season progresses. However, multiple factors influence where fishers fish on a given day. They may target shoals further offshore or specific areas known to be abundant in lobster in order to guarantee a particular catch objective (e.g. meet buyer request). Furthermore, weather, sea conditions, crew composition and money available for fuel may often also factor in deciding where to fish. Therefore, depletion of stocks within a season from near- to offshore may be difficult to assess solely on perceived interview responses. While, concerns for the state of the lobster stocks is widespread among respondents there isn’t universal agreement among fishers on changes in availability during a particular season, with some suggesting that the beginning of the season is least favorable for catch returns.

Divers in Sauteurs may venture as far as the sister islands of Carriacou and Petit Martinique. Divers from the sister islands are known to fish further north, in the waters of the Grenadines. Although these trips may simply reflect the use of traditional fishing grounds, there would presumably have to be significant incentives to render these longer journeys economical. Many dive fishers on the island are related to one another, and a number of divers have moved and dived in different communities. Those divers who moved to Carriacou cited better fishing resources than in the south of the island for doing so.

Respondents also report bathymetric changes over time in diving, particularly for lobster. Divers are more likely to have to venture into deeper water for lobster than they have historically. Divers say they are more likely to encounter favorable lobster aggregations in depths at or deeper than 30m/100ft, while conch is not generally harvested beyond this depth. It is not surprising then, that respondents cited lobster diving as a riskier activity than conch diving.

There is a difference in perceived scarcity between the two primary target species among fishers. Lobster is considered scarcer than conch while the latter is seen as plentiful, more stable or only depleted in localized areas heavily frequented by divers. However, assessing the state of lobster and conch stocks in Grenada in the absence of biological surveys is highly problematic. Landings of the dive fishery is data-poor, catch numbers, composition, size or weight are rarely recorded (Lindhop & Mohammed, 2015; pers. obs.). This is part due to the very-short and informal nature of the value chains for conch and lobster where fishers often sell directly to the end-buyer. This means that landings generally bypass points at which they may be recorded (such as fish markets) and are usually only captured reliably when exported through official channels (Lindhop & Mohammed, 2015). Nayar et al. (2009) encountered a similar problem when researching the pre-moratorium West Indian sea urchin fishery and found much of the data originated from export records. However, it is reasonable to assume that Grenada reflects similar regional trends in over-exploitation of these species (Luckhurtst & Auil-Marshalleck, 1995; Winterbottom et al., 2011).

Some respondents willingly recognize that conch and lobster are fisheries that are being heavily exploited. Overfishing on localized fishing ground is certainly a general concern for those interviewed. However, fishers contextualize this reality with concerns for livelihood dependency on fishing and the lack of alternatives in an economy plagued with high rates of unemployment. Violation of certain fisheries regulation is not an uncommon practice according to some respondents, particularly catching undersized lobsters. Such observations are in keeping with other reports of the lobster fishery and regional trends of fishing undersized individuals (CRFM, 2013; McConney, 2003).

It should certainly not be assumed that the fishery is the sole driver of these changes, or that fishers are solely responsible for such concerns. The role of value chain actors and consumers in purchasing undersized or out-of-season products that command high prices has not been examined, for example. Broader environmental and regional fisheries trends are also likely play an important role given the ecological interconnectedness of the fisheries (Ehrhardt et al., 2011; Harley et al., 2006). Indeed, changes to Caribbean marine ecosystems have been occurring for decades, of which overfishing is but one factor (Miloslavich et al., 2010). Fishers interviewed have themselves cited changes in water quality, climate and coastal development as potential causes for changes in catch. Respondents in the southern community of Calliste noted that construction of the international airport in the 1980s, which required significant coastal infilling, resulted in adverse changes to fishing grounds near the coast.

VI. Socio-economic Dimension

There are several commonalities related to the socio-economic dimension of the fishery identified by participants, which are discussed here. The structure of the market for conch and lobster are an important consideration for all fishers surveyed. This market is virtually entirely unstructured and there are several implications resulting from this for the dive fishery, all of which contribute to the short duration of fishing trips.

Individual divers are responsible for finding buyers for their *goods* or catch. In addition to cleaning catch (a particularly time consuming activity for conch), divers must allocate sufficient time after their fishing trip in order to sell this catch. Respondents cite that they are often unable to enforce desired prices for their catch or are forced to renegotiate pre-determined price agreements. Divers without infrastructure to freeze or store catch must content with perishability, which puts them at a disadvantage when trying to secure a desired price. Competition may also help drive down price especially when divers returning to shore earlier undercut price in order to displace an existing diver from an agreement with a purchaser.

Challenges exits in securing access to buyers, both at community and individual fisher levels. Proximity to tourism infrastructure positions divers closer to it at an economic advantage. At the community level, divers at Calliste and Woburn are best positioned to take advantage of their proximity to the tourism sector in the south of the island. Those diving from Carriacou and Petit Martinique rely on the tourism sector in the Grenadines and established export supply chains for their catch. Divers at Sauteurs in the north, due to distance from the main tourism, find it the most challenging to secure consistent buyers for their catch and must content with keeping product fresh for transportation. On an individual level, not all fishers are equally connected to buyers. Some fishers have existing, long-standing arrangements or have agreement with actors seeking product for export. Newer entrants into the fishery must content with pre-existing relationship and carve their own market for their goods.

Some divers do not dive outside the lobster season because market conditions for conch or fish is simply not economically viable for them and they must seek other alternatives. Partly because conch is a lower value product that divers find more difficult to sell[10]. Other divers choose not to dive conch during this time as they consider the wear and tear of heavy conch shells on their boats too problematic. Others focus on boat and engine maintenance during this period.

Profits from fishing are based on an equal share system between the keep up man, diver(s) and boat owner. Fuel and air fill costs are accounted for prior to this transaction. The boat owner receives a share of the daily catch in return for their investment even if they are not an active crew member. If the boat owner is also a diver, then they are automatically allocated two shares of the profit. The boat

[10] At the time of research conch sold for EC$10/3.70US$ /lb vs. lobster at EC$15/$5.50US$ /lb

owner is the individual responsible for boat and engine maintenance. Boat shares are typically allocated using the day's catch with each individual generally responsible for selling their allocation after they return to shore.

It was beyond the scope of this study to examine broader vulnerabilities in fishers' lives. However, there are likely to be other significant concerns that may play a role in the socio-economic dimension of the fishery. There is an ongoing threat, for example, of boats and engines theft. This has been a concern in the past in a number of communities. Boats and engines represent significant investments and are not readily recouped without financial assistance. In addition to debt owed on boats, engines or dive gear, personal debt may all play a role in increasing the economic vulnerability of fishers.

i. The co-operative at Calliste

The community in Calliste has attempted to establish and maintain a cooperative over the years but without sustained success. It even had its own air compressor for a brief period of time (though the respondent could not recall when). Approximately 10 years ago several boats and engines were stolen from the bay in Calliste where fishers kept their boats moored up. The government provided relief loans and fishers moved their boats to the adjacent bay in front of St. George's University which is well lit and has campus security, providing a safer place to moor their boats. They still operate from this bay today. This event led to a new attempt at forming a co-operative but organizing fishers has consistently proven difficult. At the time of this field research a government representative was lending assistance in trying to formalize the co-operative once more.

There is certainly no lack of aspirations for the co-operative at Calliste, including opening membership for fishers' partners/spouses as well as women who were once involved in processing seamoss. Leading members envision a number of objectives for the group including: supporting medical cost for diver treatment; supporting divers and their families if they become ambulatory; provide funds to cover search costs when divers get lost; and support the community. It has also been suggested the co-op could operate as a clearinghouse for catch, including playing a role in setting and controlling price. One respondent reflected that fishers should not be engaged in selling catch and that a co-op would be best placed to fulfill this role. The role in which a co-operative could play in controlling price is of particular interest to fishers.

B. Drivers of unsafe diving profiles

The primary research question of this study sought to determine the underlying drivers of unsafe dive profiles in the Grenadian dive fishery. These drivers are effectively vulnerabilities that directly stimulate divers to undertake unsafe diving practices. An unstructured market in which fishers operate to sell their catch, for example, is a vulnerability that drives unsafe diving practices. This section explores with these drivers. There are, however, vulnerabilities that do not act as drivers but affect the fishery and fishers themselves. The lack of access to a hyperbaric chamber, for example, does not result in unsafe diving but represents vulnerability in the access to medical care for fishers when they do get injured. These are described, in the subsequent section, as broader vulnerabilities that are framed in the context of the rights-based framework adapted from Allison et al. (2012). The final section of this chapter examines factors that aggravate the risk of diving in the fishery. These are not vulnerabilities per se but do act to compound existing ones. Diving in poor visibility or strong current, for example, increases the likelihood of getting lost at sea. Drivers or vulnerabilities that cause fishers to dive in these conditions are likely to compound the risks of diving though the conditions themselves do not represent a vulnerability faced by fishers.

Table 3 below identifies, from interview data, the drivers of unsafe diving practices in the Grenadian dive fishery. Context is provided for each driver identified in the first column. The second column identifies the reasons why a particular driver exists, and the forces that lead to the increased risk taking. In turn, the likely response of each fisher to this driver is highlighted in the third column. That is, how do fishers respond to the driver and what additional risks do they take as a result. The final column identifies the consequences of the responses, particularly in the context of diving physiology. The table shows the possible responses and consequences of identified drivers. Not all responses are necessarily exhibited at once and all-possible consequences identified do not necessarily manifest themselves at the same time. This would would depend on the scenario faced by an individual fisher or crew. Furthermore, as illustrated in the previous section, this fishery is a complex, nuanced system and there may be other factors not revealed in the context of this study.

Table 3 Drivers of unsafe dive profiles. The causes for each driver are defined and the likely behavioral responses from fishers as well as the potential consequences indicated. The combination of indicated consequences may vary according to context and may not all occur simultaneously.

			May result in a combination of					
Driver	**Cause**	**Response**	Increased probability of DCI	Increased risk of air depletion / drowning	Promotes Rapid Ascents	Increases distance from shore / medical facility	Higher exertion underwater	Promotes Shorter Interval
Last Tank 'dilemma'	Having insufficient or no catch to show for diving effort toward the end of the dive trip with one full tanks remaining on board	Fishers are more likely to exhaust their last tank while searching for catch. Fishers may also select dive sites that may be deeper and/or further out but known to be productive. Encountering a cluster of lobster or conch near the end of last dive is also cited as aggravating factor as attempts are made to collect as many individuals as possible.	✔	✔	✔	✔	✔	

			May result in a combination of					
Driver	**Cause**	**Response**	Increased probability of DCI	Increased risk of air depletion / drowning	Promotes Rapid Ascents	Increases distance from shore / medical facility	Higher exertion underwater	Promotes Shorter Interval
Market – Lack of structure	The lack of a formal economic market to sell landings creates uncertainty for fishers trying to sell their catch (e.g. inability to secure buyer).	Results in divers conducting all their dives in a short time span in order to return to shore early (dive trips typically last 4-6 hours).	✔	✔	✔		✔	✔
Market – All-or-nothing buyer request	Requests from buyers for fixed quantities of catch, especially if predicated on an all or nothing agreement.	Increases the probability of selecting known productive sites that may be deeper or further out to sea.	✔	✔	✔	✔	✔	✔
Market – Disadvantageo us negotiation position	Inability to command desired prices or forced to renegotiate existing arrangement with buyer. Being forced to offer product to buyers at a lower	Fishers respond by trying to bring in more catch in the same dive period. They may conduct more dives and/or push limits of air availability. Alternatively they may travel to sites that are deeper or further away but known to be	✔	✔	✔	✔	✔	✔

			May result in a combination of					
Driver	**Cause**	**Response**	Increased probability of DCI	Increased risk of air depletion / drowning	Promotes Rapid Ascents	Increases distance from shore / medical facility	Higher exertion underwater	Promotes Shorter Interval
	cost due to perishability.	productive.						
Market – Competition	General price instability and price undercutting by other divers	Fishers respond by trying to bring in more catch in the same dive period. They may conduct more dives and/or push limits of air availability. Alternatively they may travel to sites that are deeper or further away but known to be productive.	✔	✔	✔	✔	✔	✔
Market – Loss compensation	Attempting to make up for losses. These losses may be attributed due to poor catches from the previous day, inability to sell catch or loss of catch due to perishability.	Fishers respond by trying to bring in more catch in the same dive period. They may conduct more dives and/or push limits of air availability. Alternatively they may travel to sites that are deeper or further away but known to be productive.	✔	✔	✔	✔	✔	✔

			May result in a combination of					
Driver	**Cause**	**Response**	Increased probability of DCI	Increased risk of air depletion / drowning	Promotes Rapid Ascents	Increases distance from shore / medical facility	Higher exertion underwater	Promotes Shorter Interval
Profit sharing structure	Applies to any fishers who are not boat owners. Conversely any diver who is also a boat owner receives two shares of the profit thereby reducing their incentive to take risk.	Fishers respond with increased fishing effort in order to ensure maximum catch so as to increase individual share.	✔	✔	✔	✔	✔	✔
Social – 'Greed' (term used by respondents)	Catching more than required even after costs have been covered and profit ensured.	General increase in risk taking by diving deeper, longer, with shorter surface intervals.	✔	✔	✔	✔	✔	✔
Social - Peer pressure	Risk of being labeled	General increase in risk	✔	✔	✔	✔	✔	✔

			May result in a combination of					
Driver	**Cause**	**Response**	Increased probability of DCI	Increased risk of air depletion / drowning	Promotes Rapid Ascents	Increases distance from shore / medical facility	Higher exertion underwater	Promotes Shorter Interval
	a coward	taking by diving deeper, longer, with shorter surface intervals.						
Social – Personal circumstances	Personal factors such as mental health or preoccupation with personal matters; personal financial stressors such as debt.	General increase in risk taking by diving deeper, longer, with shorter surface intervals.	✔	✔	✔	✔	✔	✔
Ecosystem changes	Changes in the availability of catch over time either due to overfishing or other environmental changes. Localized seasonal depletion.	Increased fishing effort. Conducting deeper dives and dive trips further out to sea. Shortens time available for diving, increasing risk taking during dives.	✔			✔	✔	✔

C. Vulnerabilities in the dive fishery

Having examined the drivers of unsafe dive profiles, this section looks at the broader vulnerabilities associated with the dive fishery. Being able to identify vulnerabilities in the fishery provides a useful tool for managers by providing an understanding of these vulnerabilities and where they lie. These may be related to access to healthcare (e.g. support for divers who become disabled from a diving injury). They may be the result of a governance context related to the level of participation fishers have in the management process (Arnstein, 1969; McConney, 2003). They may also relate to the management of the fishery resource itself that may stem from the lack of monitoring of catches (Mohammed & Lindhop, 2015). This approach also allows for an understanding of where these vulnerabilities lie and perhaps who might be best suited to rectify them (Allison, 2012). Table 4 categorizes these vulnerabilities identified in the Grenadian dive fishery according to the framework proposed by Allison et al. (2012), described in Chapter 3. The identified vulnerabilities are cross-referenced with each of the four dimensions of the framework. For instance, the lack of a hyperbaric chamber represents a human welfare vulnerability, given its medical nature it might be best addressed by those in or conjunction with the healthcare sector. The lack of fishers' cooperatives, for example, represents vulnerabilities that have both a political and ecosystem management dimension as a fishers' cooperative could play an active role in both spheres.

Table 4 Vulnerability – Framework Matrix.

		Human Rights Framework Dimensions			
		Social / Human Welfare	Economic	Political	Ecosystem Management
Fisher vulnerability in the dive fishery	Access to hyperbaric facility				
	Support for injured divers				
	Lack of fishers' cooperatives				
	Resource overexploitation				
	Unstructured market				
	Fluctuations in catch prices				
	Lack of monitoring and enforcement				
	Socio-economic vulnerability (e.g. debt)				

D. Risk Factors

A number of risk factors were identified during the course of this research, which have a role in increasing the risks associated with diving in the Grenadian dive fishery. These factors, however, do not contribute to the reasons why fishers may be driven to take greater risks in the dive fishery. Some of these factors may be remedied through better practices (e.g. better equipment maintenance) while others will be factors that divers will always need to consider, such as strong currents. The management approaches of dealing with these risk factors is discussed in the subsequent chapter.

Table 5 Risk factors specific to diving in the fishery.

Risk Factors	**Implications**
Reduced visibility underwater	Reduces ability to see fellow divers underwater thereby reducing ability to deal with emergencies or increase likelihood of getting lost at sea.
Strong currents	Increases chances of exertion, running out of air, getting lost at sea.
Dive equipment failure	Increases probability of dive related accidents such as running out of air possibly resulting in rapid ascents and associated DCI or death.
Intoxication	Increases the risk of boating accidents of getting lost at sea or DCI.
Solo diving	A common feature of the fishery. Even when diving with another diver the distances

Risk Factors	Implications
	separating them would likely be ineffective in dealing with an emergency. No back up from fellow diver.
Engine failure	May result in the inability to track and retrieve diver or cause entire crew to drift at sea.
Lack of first aid oxygen	Oxygen is the standard first aid treatment for diving injuries and its timely application is critical (Levett & Millar, 2008), particularly in the absence of a hyperbaric chamber on the island. Lack of oxygen reduces effectiveness of any response to decompression injuries.
Exhausting air supply	It is not uncommon for divers to exhaust their air supply and identify it as the turn around point of a dive. It increases the likelihood of running out of air and reduces the ability to deal with an emergency.
Quality of air fills	While this study did not test air quality of the air that fishers obtain from independent compressor operators, dissatisfaction among fishers about air quality should be a cause for concern and further investigation. Contaminated air could be a risk factor easily addressed (Chin et al., 2015)

Chapter 6: Management Recommendations and Conclusions

Despite the high rates of morbidity and mortality in dive fisheries and their consequences for fishers and communities, it seems highly unlikely, given their global proliferation, that the dive genie can be put back in the bottle (Blatteau et al., 2015; Forman, 2005; Huchim-Lara et al., 2015; Ruffez, 2008). Managers and policy makers have two options when considering the practice of diving in a fishery either prohibit it or address (and regulate) existing issues. It may be convenient to conclude from the litany of issues and consequences identified in dive fisheries that standard safe diving practices are simply incompatible with efficient fishing methods. However, critical consideration must be given to the conditions under which most of these fisheries operate. Gold et al. (2000) suggested that diving related morbidity and mortality could be almost entirely prevented through safe diving practices. Indeed, there are successful examples such as the Australian and New Zealand abalone fisheries (Government of New Zealand, 2013; Haddon et al., 2014). The ecological impacts of dive fisheries must also be factored in any management decision process. Multiple fisheries that are harvested by diving are already in states of overexploitation (CRFM, 2011; Toral-Granda et al., 2008). Diving has the potential to be highly efficient in the harvesting of resources putting significant pressures on fisheries (Lindfield et al., 2014). Yet they also remain a viable alternative to other more destructive methods such as dredging as they allow for highly selective harvesting methods (Lenhihan & Peterson, 2004).

At local or regional scales, there may be attempts to ban or regulate the practice of diving (CRFM, 2015; Pakoa & Bertram, 2013). The recent *St. George's Declaration on the Caribbean Spiny Lobster*, for example, states that signatories should, *"Prohibit or regulate, as appropriate, the use of scuba diving and hookah for Spiny lobster fishing within four (4) years from the date of adoption of this Declaration" (Article 6.4.(p), CRFM, 2015).* Prohibiting diving will come with significant challenges for fisheries managers in the absence of suitable livelihood alternatives. In Grenada, approximately 85 fishers depend on diving for a livelihood, without accounting for an unknown number of dependents, supply chain actors as well as compressor operators associated with the fishery (Forman, 2005; Mohammed & Lindhop, 2015). The Grenadian dive fishery is a small but valuable component of the national fishery, which is an important contributor to the economy and food security (Kairi Consultants, 2008; SOFRECO, 2012). The dive fishery provides some export earnings, but critically supplies high-value products to the tourism sector that makes up the most important foreign exchange earner of the Grenadian economy (Kairi Consultants, 2008). A move to prohibit diving is also likely to meet stiff resistance from fishers themselves and may ultimately prove a politically unpalatable option.

Transitioning gear type, while not impossible, would also present its own challenges. Traps, for example, are proven alternatives for lobster fishing. However, significant cost, acceptability and ghost fishing of gear are challenges that accompany efforts to change gear types (Ehrhardt, et al., 2011; McConney, 2003). Merely shifting gear will do little to address existing challenges, such as funding, capacity, enforcement and monitoring, faced by fisheries managers (Salas et al., 2007). In Grenada, any prohibition on diving will also need to consider the multi-species nature of the fishery, an issue not solved by simply changing gear type for one target species. Furthermore, the current trend to promote SCUBA-based lionfish culls and derbies among fishers would run counter to any attempts at prohibiting a dive fishery or changing gear use (Côté et al., 2013; pers. obs.).

A. Management Recommendations

While there are management options for the Grenada's dive fishery, reconciling safe diving practices concomitant with fishing is a certainly not a simple prospect and must be considered in the wider context of conch and lobster stock management efforts. There are three potential pathways that can be identified from the research data to improve safety in the Grenadian dive fishery. One is to address the drivers that play a direct role in stimulating unsafe diving practices. Two, address the broader vulnerabilities that impact the dive fishery and reduce socio-ecological resilience (both internal and external to the fishery). The third approach is to mitigate existing risk factors present in the fishery. Assessing precisely how these interventions may be borne out is beyond the scope of the research outlined in this study. Table 6, however, provides possible insights.

Table 6 Context for the three pathways to addressing safety in the Grenadian dive fishery. *Implies participation of fishing communities in each scenario.

Pathway	**Intervention Level***	**Timescale**	**Example**
Addressing vulnerabilities	Governance and policy	Long term (years)	Socio-economic vulnerabilities
Addressing drivers of unsafe dive profiles	Regulatory and management	Medium to Short term (months to years)	Disadvantageous negotiating position vis-á-vis buyers
Mitigating risk factors	Regulatory and management	Short term (weeks – months)	Field access to oxygen for first aid response

Dealing with the broad vulnerabilities identified will likely require intervention at the governance and policy levels and take substantial time to achieve (Allison & Ellis, 2001). Therefore, dealing with these vulnerabilities will not resolve problems in the dive fishery overnight and many may not address dive-specific concerns. Yet, managers should consider addressing them, as they likely impact other fisheries in Grenada more broadly. Tackling the drivers that lead to unsafe dive profiles is not a straightforward task. However, these can and must be addressed to ensure safety and sustainability in the fishery. These can be dealt with in tandem with broader vulnerability-reduction efforts and in direct collaboration with fishers and industry stakeholders. Dealing with price issues, for example, may be addressed in relatively quickly among stakeholders, if they can be brought to an agreement. Even if on a temporary basis as an effective, low-cost way to alleviate some pressured on the risk associated with diving. Mitigating risk factors likely represent the cheapest and quickest way to address some of the risks of diving in the fishery but they are unlikely to be effective in the absence of broader management interventions.

The recommendations are presented in order of their relative complexity and do not indicate mutual exclusiveness when being considered for implementation. In other words, installing a hyperbaric chamber can occur concurrently to improving market structure for fishers. In fact, care should be taken when considering such approaches as some interventions may unintentionally result in greater risk taking. Forman (2005) suggests that some fishers would likely take more risks knowing that treatment would readily available, a finding reflected in interview responses from this study. The installation of a hyperbaric chamber should therefore be considered in conjunction with improved training and awareness for dive fishers (Forman, 2005).

A central premise outlined above is that the dive fisheries represent a unique system in which fishing effort exerted is tied to the physiological risk from diving. The principles of diving physiology make this an inevitable yet crucial principle in addressing the drivers of unsafe dive profiles. If the drivers of increased fishing pressure can be managed, then so too can the physiological risks. This research project identified socio-economic drivers as the primary concern for driving unsafe dive profiles and, to a lesser extent, ecosystem changes.

I. Socio-economic Drivers: A co-management model?

The analysis of interview data identifies socio-economic factors as key drivers of unsafe dive profiles. The economic and market forces that influence dive behavior take multiple forms, such as disadvantageous negotiating positions or uncertainty in securing buyers for catch (Table 3). Fishers from several communities have identified the potential for a co-operative model, though only the dive fishing community at Calliste seems to have had a history of organization. This cooperative has waxed and waned over the years with current attempts to re-establish it ongoing. Self-organization in the form of co-operative arrangement has the potential to provide certain benefits such as greater participation in management processes, better market or price control and information sharing (Basurto et al., 2013). Participants in this study have identified these benefits, as well as the ability to pool resources for search and rescue efforts for lost-at-sea divers.

A fishers' cooperative seeking to play a role in the management of the fisheries, such as addressing the nature of the market in which lobster and conch are sold, would likely have to consider a form of co-management arrangement by which the government would have to share the authority and responsibility of managing the fishery resource with fishers. Any co-management arrangement will require support from the government in order to be successful (Armitage, 2007; Chuenpagdee & Jentoft, 2007). A number of other challenges would need to be overcome if these benefits were to be realized through co-management. In Grenada, both fishers' co-operatives and co-management have had limited successes historically (Finlay et al., 2003; McConney & Baldeo, 2007). Fishers interviewed for this study, for example, point out that some fishers are only likely to come on board once they see and understand the potential of a co-operative. Co-management efforts in the beach seine net and trammel net lobster fisheries in Grenada were unsuccessful and show that such an arrangement in the dive fishery would need to be considered with care (Finlay et al., 2013; McConney & Baldeo, 2007). Indeed, successful co-management efforts in the Eastern Caribbean tend to be the exception rather than the rule, the leatherback sea turtle ecotourism initiative at Matura, Trinidad and the Soufriere Marine Management Area (SMMA) in St. Lucia are notable examples where co-management has had greater success in the region (Cox & McConney, 2015; McIntosh & Renard, 2010; Sandersen & Koester, 2000).

Crisis triggers that can lead to self-organization and co-management arrangements are clearly evident in the Grenadian dive fishery (Chuenpagdee & Jentoft, 2007). Fishers at Calliste responded to the thefts of their fishing boats by attempting to organize and seek government input. Issues surrounding resources for search and rescue and supporting injured divers also seem to be key motivators to them. Although, the recognition of diving as dangerous does not in itself appear to be a trigger that would drive co-management. While fishers in other communities have identified the potential for self-organization during the interview responses, only those at Calliste seem to have been active in such a process. Even though these same crisis triggers exist in other communities included in the study. Therefore, even if a sustained and successful effort were to emerge from Calliste, questions remain as to how other communities would view this and whether this model would be suitable in communities with much fewer divers. A consideration would be whether such a co-operative should include all fishers across all dive-fishing communities, reducing the risk of one co-operative operating in the same unstructured market all individual fishers now content with. Furthermore, any potential co-operative will need to consider whether its resources should be spent the consequences of unsafe drive profiles, addressing the factors that result in these practices in the first place.

Any attempts to promote the self-organization of fishers would require careful consideration of what has caused such arrangements to stall in the past, some of these are reflected in the current research. McConney and Baldeo (2007) found that these include, among others, weak legal and institutional support, uncertainty among fishers about co-management and, a general lack of leadership within communities to undertake and sustain such efforts.

Co-management has the potential to lighten the burden of management from fisheries managers (Amitage et al., 2007). This would presumably be an attractive proposition for managers of Caribbean fisheries given the challenges they face (Salas et al., 2007). However, the history and existing evidence of co-management in Grenada would suggest that initial efforts to do so in the dive fishery would likely increase the burden for fishery managers, at least in the short-term.

Identifying and understanding the conditions that precede co-management will be crucial for success (Chuenpagdee & Jentoft, 2007). Despite the livelihood challenges and dangers, fishers in Grenada view diving as an activity that they are proud of and have an affinity for, nurturing the motivations for those who seek to self-organize should be viewed as essential by those who seek to support such efforts.

A co-management model has the potential to address the economic drivers of unsafe dive profiles by bringing structure to the market for lobster and conch, giving fishers the potential to act as a coordinated clearinghouse for their catch. These would, as the interview responses suggest, greatly reduce the pressure to dive as intensely as they currently do.

II. Ecosystem Drivers

This study cannot be conclusive about the degree of changes in the state of lobster and conch stocks that fishers in Grenadian dive fishery have experienced over time. Similarly discerning the causal factors of these changes (e.g. overfishing, climate change) or their precise impact on driving dive behavior is also problematic (Miloslavich et al., 2010). There is evidence from fishers that they have experienced change, particularly in the lobster fishery as well as overexploitation at localized and seasonal scales. Furthermore, responses from older fishers suggests that greater dive effort is now required to bring catch back to shore, and certainly not in the quantities that they experience when they were younger. The sequential geographic and bathymetric depletion reported by fishers here has been evidenced in the sea cucumber fisheries of the Pacific and Indian ocean, where diving is a prevalent method of harvest (Eriksson et al., 2012, Pakoa & Betram, 2013; Toral-Granda et al., 2008).

The initial observation suggests that increasing resource scarcity would drive the risk that fishers take when diving, changes that have occurred slowly over a number of decades (the dive fishery began in the 1970s). The role of 'shifting baseline syndrome' where one generation perceives the fishery conditions as normal because they do not have the same experiences as the previous generation may also play a role here in two ways (Pauly, 1995). Firstly, it may play out in the classical sense where new entrants into the fishery consider the current conditions as the normal baseline from which to make judgments about the health lobster and conch stocks. Secondly, this principle can be considered from the perspective of diving. New entrants into the fishery do not have the luxury to gain experience in shallower waters closer to shore in the same way, more experienced, older divers have. In other words, the baseline for what new divers consider dangerous is different than for divers who fished 20 or 30 years earlier.

Allison and Ellis (2001) note that fishers alter their responses to changing availability of resources with a wide range of adaptations such as changing fishing area or gear type or ensuring gear types that allow mobility to other types of fishing. This is where a broader assessment of livelihoods and vulnerabilities in the fishery would shed light on how dive fishers in Grenada may respond to increased resource scarcity and at which point they may do so. In other words, how much more diving risk would they be willing to accept before seeking alternative livelihood strategies.

Addressing ecosystem based drivers of diving risk will require improved fisheries management such as monitoring and enforcement as well as addressing the concerns related to changes in the marine environment (Lindhop & Mohammed, 2015; Miloslavich et al., 2010). Here co-management may also play a useful role in engaging fishers in the active management of the lobster and conch fisheries, in addition to addressing economic risk drivers. Better management of stocks by moving away from what are now open access and poorly enforced fisheries would have the benefit from greater fisher participation (Chuenpagdee and Jentoft, 2007). If these were to lead to healthier stocks then this would have the potential to mitigate further ecosystem driven risk behaviours and perhaps over time even reverse them.

III. Mitigating existing risk factors

Mitigating the risk factors identified by fishers in Table 4 may provide a cost-effective way to improve safety in a relatively short time frame. Some of these may be considered “low-hanging management fruits,” and while their effectiveness should not be underestimated on one hand, they detract from addressing more significant concerns in the fishery that drive risky dive behavior on the other.

Timely administration of pure oxygen, for example, is a critical first response tool for diving injuries (Levett & Millar, 2008). Having emergency oxygen available on vessels as a safety requirement or on shore would be highly beneficial and effecting in treating injuries, particularly in the absence of a hyperbaric chamber on the island (Blatteau et al., 2015). The caveat is that its presence must not be used to further push diving limits (Forman, 2005).

Another example would be to improve responses for fishers lost at sea or experiencing engine failure in order to improve the chances of survival and recovery. A simple cost effective approach highlighted by one respondent would be to implement a system where individuals/boats heading out to sea would indicate to someone on shore where they planned to fish and for how long. This would allow searches to be triggered and initiated in a timely fashion and place resources (e.g. fishing boats involved in a search) in the correct location. This may also provide a proxy for measuring fishing effort in the fishery. While such a system could be a beneficiary of having a co-operative, it can be implemented in its absence and be guided by key community members or via personnel at fish markets where some divers operate.

Other mitigation measures may be more difficult to address and depend on other management interventions. Reduced visibility and water quality where it is the result of natural variations in ocean conditions, for example, is not something that can be readily managed nor can conditions caused by long-term anthropogenic environmental degradation (Miloslavich et al., 2010). However, addressing the economic vulnerabilities and market uncertainties in the fishery may remove the pressure for fishers to dive in conditions that are less than favorable. Policies in resource conservation, for example, can reduce the number of suitable fishing days forcing fishers to sea when they may otherwise stay in port (Kaplan & Kite-Powell, 2000).

Education and awareness programs on dive theory, procedures and practices may also help address misconceptions and certain risk behaviors such as solo diving and the practice of using tanks until they are nearly empty (Blatteau et al., 2015; Egstrom, 1993; Forman, 2005). Grenadian fishers have tremendous experiential knowledge of diving, however, without altering the underlying drivers that promote dangerous practices in the first place, education initiatives are unlikely to be effective in the long run.

B. Methodology: Limitation and Strengths

A more detailed analysis of livelihood vulnerabilities and broader examination of the fishing sector would refine the results and possibly reveal other factors that drive unsafe dive profiles and affect socio-economic resilience in the fishery (Allison & Ellis, 2001; Allison et al., 2012; Andrew et al., 2007).

While a qualitative methodology allows contextualization of the fishery under study its limitations must be recognized (Bradely et al., 2007). The subjective responses of fishers are subject to errors in accuracy and recall (Lewison et al., 2011). A key limitation, for example, is trying to determine changes in the resource over time. However, the paucity of landing data and absence of any survey data on fishing grounds makes it almost impossible to determine temporal trends within the scope of this project. Similarly, dive information for the depths, duration and surface intervals are largely based on recalls making it difficult to draw reliable statistical conclusions without conducting dive profile logging experiments (Lewison et al., 2011). The interview responses confirm that Forman's (2005) prevalence results do not seem to have improved. However, collecting statistical dive data is not required to confirm that fishers are undertaking unsafe dive profiles; the ongoing incidence of injuries and deaths in the fishery confirms this.

Despite these limitations, an ethnographic approach provides a valuable insight into the dive practices undertaken in the fishery, particularly since this aspect of dive fisheries remains understudied (Barratt & van Meter, 2004; Huchim-Lara et al., 2015). It allows this study to build on existing quantitative work and place it in the context of the fishery (Forman, 20015). Furthermore, it provides a means with which to validate to fishers' responses (Russell, 2006). The ethnographic approach also recognizes Fishers Ecological Knowledge (FEK) as a valid and valuable tool in research; particularly the absence of long-term, reliable, detailed fisheries catch trend data as is the case here (Johannes et al., 2000).

C. Future research

The evident complexity of even a small dive fishery illustrates the need for long-term efforts to address the challenges faced by fishers that are far beyond the scope of a single graduate research project. While much remains unknown about Grenada's dive fishery, the he management recommendations above provide an initial road map for action towards improved safety and sustainability. Dive fisheries are incredibly diverse in their target species, global distribution, type of diving and socio-economic arrangements under which they operate (Huchim-Lara et al., 2015). There is a clear need for more further research into dive fisheries particularly if there is to be a deeper understanding of how they function and their implications for people and ecosystems. Table 7 provides a starting point and rationale for future avenues research into dive fisheries.

Table 7 **Future research agendas for dive fisheries.**

Research Focus	**Rationale**
A global analysis	Provide a global overview of the state and trends in dive fisheries Bassett, Winkler, Chin, Allison & Joo (in preparation)
Mixed-method approaches	Provide more flexible tools to address the interdisciplinary needs of dive fisheries research (Creswell, 2003).
Dive & fishing behavior	Understand relationship between dive behavior and decompression sickness in different types of diving (Huchim-Lara et al. 2015). Collect data logging dive profiles to evaluate diving risk more accurately (Chin et al., 2015). Understand complex decision-making process fishers use (Béné & Tewfik, 2001).
Small-scale fishery context	Contextualizing dive fisheries in small-scale fishery context, particularly in the developing world (Andrew et al., 2007)
Alternatives	Policy and methodological alternatives (McConney, 2003)
Education and Interventions	Improving dive training through educational workshops. Teaching first aid interventions such as in-water recompression, where appropriate (Forman 2005; Blatteau et al., 2015)

There are grave human and ecological consequences for those who pursue their livelihoods based on compressed air diving as they seek marine living resources that are often poorly managed and overexploited. Similarly, fishers in the

Grenada dive fishery currently face daily risks of decompression injuries and being lost at sea in a fishery where little is known about the state of the resource, and that has minimal management intervention. Little is known about what forces drive fishers take such risks and what the management approaches to resolve the issue might be. The ethnographic approach employed here allowed the researcher to examine these issues through interviews with fishers as well as direct and participant observation. This account of the fishery provides a first known record of the practices of dive fishing in the Grenadian Caribbean Spiny Lobster (*Panulirus argus*) and Queen Conch (*Lobatus gigas*). It is hoped that this research will prove valuable to fishers and managers in the future.

This study identified primary drivers of unsafe dive profiles, vulnerabilities relevant to the fishery as well as risk factors, all of which play a role in maintaining an unsafe and potentially unsustainable fishery. Economic drivers, particularly where the market for selling catch is concerned, seem to the most common reason why divers conduct so many dives in such a short timeframe. Left unchecked, compressed air fishing has the potential to deplete resources effectively and coupled with environmental degradation may lead to unfavorable ecological changes for the fishery. Changes in availability of fishery resources over time, geography and depth are likely to contribute to long term trends towards increasing diving risk, though further research would be required to prove this conclusively.

Banning the dive fishery or transitioning the fishery to another gear type is currently an unrealistic, perhaps even undesirable prospect given that it would still require managers to address underlying socio-economic vulnerabilities faced by fishers. Therefore, managers have three strategies they may employ. One, managers can address the vulnerabilities that impact fishers. Two, they can deal with the underlying drivers of unsafe dive profiles identified by this research. Three actively mitigate factors that aggravate existing dive risk. Each of these strategies presents its own difficulties and effectiveness in their ability to reduce the risk in diving and should not be considered as separate approaches.

Alleviating these vulnerabilities would not only promote a safer fishery for divers but also allow them to engage and be "effective and motivated resource stewards" (Allison et al. 2012; p.19). Given the interest in some fishing communities for co-operative arrangements, the potential for co-management based on these co-operatives provides a possible pathway forward to such a goal. Diving also allows for highly selective harvesting and may therefore be a tool in the sustainable fisheries toolbox if it can be managed effectively. Notwithstanding significant challenges in achieving this coupled with the economic importance and demand of the high-value Caribbean Spiny Lobster and Queen Conch, it is should not be inconceivable that the Grenadian dive fishery could be a model for a safe and sustainable dive fishery for others to follow.

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