Great Risk, Great Reward:
The Global Extent and Nature of Compressed-Air Dive Fisheries

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Abstract

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Dive fishing is the practice of harvesting marine or aquatic species through the use of an Underwater Breathing Apparatus (UBA), such as SCUBA or hookah. Prior to this study, dive fishing has not been addressed as a distinct fishing method with unique considerations for achieving sustainability. This project represents the first attempt to understand and describe the general nature, extent, and sustainability outcomes of dive fisheries globally. Through a mixed-methods review of relevant multi-disciplinary scientific literature, 118 dive fisheries located in 60 countries were identified. This inventory reflects incomplete treatment of dive fisheries in the

scientific literature and suggests that dive fisheries are understudied, particularly in lower-income countries. This analysis finds that most dive fisheries in the literature are small-scale commercial fisheries targeting high-value, benthic invertebrates. Dive fishery descriptions, combined with insights from data on stock status and dive fisher morbidity and mortality (M&M), suggest that dive fisheries present both great risk and great reward to their user groups and communities. While a small number of fisheries report relatively safe operations, others present M&M levels that provide additional support for the assertion that dive fishing may be one of the most dangerous peace-time occupations documented. Of the fisheries with reported stock status, over half are depleted or over-exploited, and serial localized depletion is a common concern across fisheries. M&M levels are consistently lower and stocks are consistently healthier in fisheries in higher-income countries.

As a selective and efficient method for the harvest of high value species, dive fishing holds potential for sustainability across social, ecological, and economic dimensions; however, this outcome is not commonly realized. By shedding light on dive fisheries' potential for both great risk and great reward, this study illuminates the need for greater attention to this unique form of fishing. The initial inventory of dive fisheries provides a foundation of knowledge from which further research and sustainable management practices can be developed.

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DEDICATION

To my mom, Peter, Serena, and Kekoa

1. INTRODUCTION

1.1 *Problem statement*

Fisheries exist in myriad varieties and provide well-being to millions of people around the world. Accordingly, sustainability is the central concern of fishery governance and management. However, widely accepted best practices for management have largely been developed based on industrial fisheries that target pelagic species, reflecting the needs of only a subset of fisheries (Orensanz et al., 2005). Dive fishing, on the other hand — which requires the use of an Underwater Breathing Apparatus (UBA) such as SCUBA or hookah to access marine or aquatic resources — is one method of fishing for which best management practices are not well understood.

This distinct harvest method confers a variety of implications for sustainability. In particular, the selective and efficient nature of the practice suggests potential benefits for economic and ecological sustainability (Lenihan & Peterson, 2004). However, these same qualities can lead to over-exploitation (e.g. Monnereau, 2012), localized depletion (e.g. Conand, 2008), and the illegal harvest of rare or endangered species (e.g. Sabetian & Foale, 2006) if not effectively managed. Additionally, the direct contact between fisher and the marine or aquatic environment also poses substantial physical hazards to divers (e.g. Chin et al., 2015). Reduced stock health and loss of social capital due to injury or loss of life can present potential stressors to sustainable functioning of dive fisheries as social-ecological systems.

In practice, dive fisheries have largely been viewed as problematic fisheries (e.g. Pakoa & Bertram, 2013) though sustainability has been achieved in some cases (Mayfield, Chick, Carlson, & Ward, 2011; Rumble & Hebert, 2011). Lacking specified best practices, many managing bodies have opted to ban dive fishing to avoid negative outcomes, such as physical harm to divers or

overfishing of stocks (CRFM, 2011). However, a complete ban may undercut the potential of the practice to provide essential well-being to local communities and may lend itself to illegal harvest.

Despite the varied potential and observed degrees of sustainability and striking rates of physical danger reported in dive fisheries, sustainability outcomes and levels of vulnerability to potential stressors associated with this resource harvest method have not been addressed on a broad scale. Without understanding the global extent of the practice (exposure to hazards), role of the practice in communities (sensitivity to hazards), and context the practice exists within (capacity to adapt to hazards), the extent of vulnerability to hazards and resulting risk posed by the practice cannot be understand. Similarly, without examination of sustainability outcomes across dive fisheries, a grounded understanding of dive fishery sustainability cannot be achieved.

Thus far, dive fishing has not been explicitly addressed as a fishing method with unique characteristics and sustainability considerations. As a result, we do not know the global extent of the practice, general characteristics of dive fisheries, or patterns in sustainability outcomes. As is common with small-scale fisheries (SSFs) generally, a lack of attention, and resulting lack of information, can perpetuate an attitude that the practice is not substantial enough to study (Govender, 2013). Yet, if a practice is not well-understood, it is not possible to know if it warrants additional attention.

As an initial step toward remedying the research gap, this review assesses the current state of scientific knowledge on dive fisheries and identifies critical holes in our understanding that need further attention. Specifically, this study aims to (a) establish an inventory of global dive fisheries as represented in the scientific literature, (b) provide a basic description of general characteristics of identified dive fisheries via a quantitative literature review, (c) interrogate sustainability outcomes in identified fisheries through analysis of stock health and diver M&M levels, and (d)

identify common themes across the dive fishery literature via an inductive review. While supplying a comprehensive inventory and characterization of all dive fisheries is not feasible based on information available in peer-reviewed and grey literature, review of this body of knowledge allows for a more nuanced approach to investigating dive fishery systems and identifying areas for future research and management.

1.2 *Fishery sustainability*

Sustainability is the primary objective of fishery governance. In recent traditions of fishery management, ecological sustainability has been the primary goal, but the importance of social and economic sustainability has been increasingly acknowledged in recent years. Within social-ecological systems science, sustainability is described as having three interconnected and interdependent pillars: social, economic, and ecological sustainability (Asche et al., 2018). In this study, we employ this general framework and adopt a definition of sustainability that reflects both the interplay of the three pillars and their synergistic outcome.

1.2.1 Provision of inclusive well-being

Sustainability is the state in which inclusive well-being does not decline over time (Matson, Clark, & Andersson, 2016). In turn, human well-being is commonly seen to consist of five primary qualities: (1) basic material for a good life, (2) health (mental, physical, spiritual, and emotional), (3) good social relations, (4) security, and (5) freedom of choice and action (Millennium Ecosystem Assessment, 2005). These components of well-being relate to personal and social functioning, and express what a person values doing or being (Sen, 1999). Definitions of well-being and its constituent parts vary across communities and cultures (Harthorn & Oaks, 2003; Lupton, 1999; Nelkin, 2003). In particular, health is conventionally considered a physical quality, but many cultures, including several indigenous groups, consider psychological, social, and

cultural aspects of health as inherently inter-connected with physical health (Arquette et al., 2002; Garrett, 1999; Harris & Harper, 1997; Wolfley, 1998).

This definition of sustainability communicates the importance of social and economic sustainability in addition to and in combination with ecological sustainability. By specifying that provision of well-being is 'inclusive,' Matson, Clark, & Andersson (2016) centralize the fact that increased well-being for one or more groups concurrent with decreased well-being for one or more other groups, creates social disturbance and reduces sustainability of the social-ecological system as a whole. Sufficient social, human, natural, and manufactured (or economic) capital are all required for well-being to be achieved and all are derived from or reliant on services provided by the natural world (Millennium Ecosystem Assessment, 2003). In contrast, poverty is defined as the "pronounced deprivation of well-being" (Millennium Ecosystem Assessment, 2003) and occurs when ecosystem services are not available or accessible.

While essential for deriving well-being, the existence of ecosystem services does not guarantee well-being. Rather, social factors (i.e. societal characteristics, institutions, instruments, organizations, technology, practices, and socio-cultural norms) determine whether the well-being potential of ecosystem services is realized and by whom (Fisher et al., 2013). In other words, the process is 'socially mediated' and fishing is one mechanism by which ecosystem services are transformed into well-being. Accordingly, fishery sustainability is essential for continued provision of well-being to people around the world in the form of sustenance (protein and micronutrients), livelihoods, social connections, cultural values, a sense of place and self, and other ecosystem services.

1.2.2 Resilience, vulnerability & risk

Resilience, or a system's ability to make necessary adjustments to maintain core functions when faced with perturbations or stressors, is a core component of sustainability (Walker & Salt, 2012). A system's resilience is also determined by social factors. Vulnerability refers to a lack of resilience and includes three constituent parts: degree of exposure, degree of sensitivity, and capacity to adapt to the stressor (Adger, 2006). The synergistic outcome of system vulnerability and a stressor is risk, which acts counter to sustainability. In contrast, increased system resilience to said stressor has a positive influence on sustainability. Each of these components of sustainability can vary for different parts of the system and different pillars of sustainability.

1.2.3 Health & social sustainability

The importance of social sustainability in fisheries has seen a surge of recognition in recent years with a wave of investigative reports into the treatment of fishermen at sea. As a result, the prevalence of human abuses and physical danger within the fishing industry has received increased public attention. In June 2014, *The Guardian* documented the squalid living conditions of fishers on Thai vessels, who were held in a form of modern slavery (Hodal, Kelly, & Lawrence, 2014). The *Associated Press* followed in September 2016 with an exposé on foreign fishers confined on vessels based in Hawaii for years (Mendoza & Mason, 2016) and additional reporting has followed (e.g. Murphy, 2018). While fishing has long been recognized as one of the most dangerous professions in the world, human rights and social justice abuses have only recently received widespread attention. However, this new attention has not been directed at all fisheries equally.

Human health is recognized as an important component of social sustainability (Dempsey, Bramley, Power, & Brown, 2009). Negative impacts of recurrent death and injury within a community can be overt – such as reduced social, emotional, or material support due to the loss of

a family member or friend or the increased burden of caring for a disabled loved one. However, frequent loss of life and injury can also have less-apparent ripple effects through communities. Disease and injury affect patients' emotional health, family dynamics, and social networks (Schulte, 2005). Social costs of work-related illness and injury have not been extensively documented, however, Dembe (2001) has developed a conceptual framework for identifying and analyzing the "hidden" social consequences of occupational injuries and illnesses. The study finds that occupational injuries and illnesses produce a variety of social consequences involving complex and multifactorial relationships amongst administrative activities, medical care experiences, domestic function, psychological and behavioral responses, stress, vocational function, rehabilitation, and equity and social justice.

Human health and safety in the context of fisheries has also received recent attention (King, Kilpatrick, Willis, & Speldewinde, 2015; Matheson et al., 2001). In their scoping review, Woodhead et al have more specifically examined health and safety within the context of fisheries (Woodhead, Abernethy, Szaboova, & Turner, 2018). The authors highlight that healthy people are essential for maintaining a sustainable fishery, yet fishers often experience poor health. While dive fishing may hold potential to provide economic gains, loss of life associated with the process may in some cases counterproductively reduce other aspects of well-being.

1.3 *Physical risk in dive fishing*

Diving is inherently dangerous due to the physiological strain of breathing compressed air at depth. Rigorously researched dive tables (e.g. Navy dive tables) provide guidelines for safe diving practices. Dive profiles of greater depth or duration than advised by appropriate guidelines can lead to morbidity (temporary or long-term injury), disabling morbidity (injury that results in decreased mobility and function, often inhibiting individuals from continuing to dive or work in

other capacities), or mortality (death) via several physiological mechanisms (Buzzacott, Denoble, Dunford, & Vann, 2009; Gold, Geater, et al., 2000; O. Huchim-Lara, Salas, Chin, Montero, & Fraga, 2015). Many of the dangers associated with diving are due to compression of gases within the body under increased pressure at depth.

Injuries can take several different forms, affect most parts of the body, and result from single events or repeated stresses. Merck Manual's, "Overview of Diving Injuries," (Bove, 2017) describes several typified forms: Barotraumas occur when gas-filled spaces expand upon ascent or constrict upon decent and cause damage to tissues. Ears are the most commonly affected areas, but barotrauma can also occur in the lungs, sinuses, face, gut, teeth, and eyes. Decompression sickness (DCS), commonly called 'the bends' results from the release of dissolved nitrogen in blood and tissues when a diver ascends too quickly for the nitrogen to escape via respiration. Both barotraumas and DCS can result in arterial gas embolism (AGE), which occurs when gas bubbles escape to arteries and then block blood passage. Together DCS and AGE are referred to as decompression illness (DCI). Other conditions that can result from pressure changes while diving include gas toxicity (oxygen, carbon dioxide, and carbon monoxide) as well as nitrogen narcosis or 'rapture of the deep' in which divers at depths generally greater than 100 feet experience euphoric and disorienting feelings that can cause poor decision-making and dangerous dive behavior. The disorders described above can occur during a single incident, but other disorders develop over time with repeat exposure. For example, dysbaric osteonecrosis (DON) results in a weakening of the diver's bones (ILO, 2000).

Dive fishers may experience non-barometric hazards as well due to exposure to marine conditions and animals or from their reliance on a detached air source. Hypothermia and heartbeat irregularities can result from diving in cold water. Bites and stings from marine life, particularly

sharks, can also pose risks. Lastly, dangers inherent to working at sea that are common in other types of fishing also affect dive fishers. These hazards include susceptibility to inclement weather; potential for drowning due to injury or impairment such as drowsiness, drug use, loss of consciousness, panic, or disorientation; and equipment malfunction sometimes resulting in an inability to return to land. In addition, divers using surface-supplied compressed air can suffer injury or death if their air supply is disconnected or contaminated with engine exhaust (ILO, 2000).

Dive fishers face greater risk than recreational divers because they are exposed to and are more vulnerable to hazards. While dive fishers are susceptible to the same hazards as recreational divers, they are more exposed to these hazards due to the challenges of operating fishing gear at depth and from spending far more time at depth. Vulnerability of dive fishers to these hazards is heightened by socio-economic incentives to push the limits of safe diving to harvest more resources, generate more income, or access more food. Thus, dive fishers are at greater risk to the hazards of diving because they rely on the practice to maintain their well-being. This theoretical understanding of dive fisher risk is supported by data reflecting injury and death in recreational diving. In an analysis of recreational diving-related mortality in the US in 2014, Divers Alert Network (2016) noted that divers engaged in spearfishing, hunting, or collecting game were at an elevated risk of running out of air, and the physical requirements of the hunt and tools carried by dive fishers contributed to an increased workload and physical strain. The seasonality of dive fishing can also contribute to increased diver risk as divers who have not maintained their diving skills throughout the year will experience a greater underwater workload (Divers Alert Network, 2016).

International agencies and organizations aimed at addressing occupational or diving safety concerns have given dive fisheries little attention. Divers Alert Network (DAN) is the largest

association of recreational divers worldwide and supplies insurance, travel assistance, and education to its members, who often include professional and technical divers (DAN, n.d.). However, DAN's provision of resources and services largely does not extend to dive fishers. DAN is only available in the US and Canada, though Independent DAN providers operate as non-profit organizations in several regions around the world, such as Europe, Brazil, Southern Africa, Japan, and Asia-Pacific (DAN, n.d.). DAN tracks and reports diving-related deaths but only for the US and Canada, and only for recreational diving accidents (Divers Alert Network, 2016). Similarly, the Undersea Hyperbaric and Medical Society (UHMS) focuses primarily on dive medicine in relation to recreational and technical divers and has put little effort toward addressing the safety of dive fishers. One notable exception was a 2001 workshop session held at the UHMS conference dedicated to dive fisheries. More recently, there has been a push from individual UHMS members to increase the focus on dive fisheries, which has resulted in several talks and papers on the topic (e.g. Bassett, 2015; O Huchim-Lara et al., 2013; Oswaldo Huchim-Lara, Fraga, & Salas, 2012).

In contrast, the International Labor Organization (ILO) has acknowledged the hazards of dive fishing in their International Hazard Datasheets on Occupation for Indigenous Fisherman Divers (ILO 2000). The ILO also adopted a Work in Fishing Convention (No. 188) in 2007, which went into effect in November 2017, a year after its 10th ratification. The convention sets standards for improving working conditions in the fishery sector, but does not address dive fishing specifically.

While participation rates and incidents of morbidity and mortality are monitored and published for recreational and technical diving in some regions, there is less data collection and organization for commercial and subsistence dive fishing. Incidents of death and injury have been reported for several dive fisheries, but there is no centralized database or repository containing data on dive fishing effort or incidents globally. Without a broader understanding of the extent of

the practice and its impact on divers, efforts to address the high rates of death and injury will be inefficient at best and non-existent at worst.

1.4 *Fishery management*

As is common in the historic treatment of fisheries, large-scale and industrial fisheries have tended to receive the most attention. Historically, fishing methods commonly employed in industrial fishing – such as trawl and purse seine – have received ample attention from researchers, managers, and governmental and non-governmental organizations. In contrast, small-scale fisheries (SSFs) and fishing methods conducive to small-scale operation have historically received less attention (Govender, 2013). Highly variable in nature and often geographically remote, SSFs (and their social and ecological impacts) are generally less visible and less accessible for research and management purposes. Numerous studies have shown that SSFs are equally as important as large-scale fisheries, in the magnitude of their contributions to human well-being globally (e.g. Jacquet & Pauly, 2008; Thomson, 1980). However, pervasive omission of SSFs from reporting and study has perpetuated a narrative that they are not important for consideration (Govender, 2013). Recent calls for attention to SSF research and management highlight that they are of critical importance to communities globally and warrant focused efforts (Teh, Teh, & Sumaila, 2013).

Dive fishing is one such fishing method that has received relatively little attention from researchers and managers. Despite dive fishing's high levels of risk as well as the potential for either ecological sustainability or over-exploitation, the practice remains minimally addressed by researchers in relevant fields such as fisheries management, occupational health, and development. Without acknowledging dive fisheries as a specific type of fishery with particular considerations for both human well-being and resource health, widespread and efficient improvements to ensure sustainability will be challenging if not impossible.

1.5 *Research objectives*

This scoping study takes a first step toward remedying the oversight of dive fishing as a unique fishing method with distinct considerations for sustainability. The aims of this project are two-fold: First, development of an inventory and basic characterization of dive fisheries globally is intended to provide foundational, descriptive knowledge of dive fisheries on a broad scale. Compiled through systematic review of peer-reviewed and grey literature, this first-order description aims to illuminate the current state of scientific knowledge and documentation of dive fisheries, providing insights into both the extent of information available to dive fishery managers and stakeholders as well as gaps in said information. Better understanding both the nature of dive fisheries and how they are represented in scientific literature will inform an improved understanding of research needs and management considerations. Second, collection of available data on morbidity and mortality in dive fisheries and status of targeted stocks will provide baseline indicators for social and ecological sustainability outcomes in dive fisheries. This approach allows for an initial analysis of patterns of sustainability outcomes across dive fisheries, as well as identification of gaps in data for more thoroughly assessing sustainability outcomes.

As an initial foray into describing dive fisheries and understanding their sustainability outcomes in practice, for pragmatic reasons, this study is limited to analysis of scientific literature. Thus, this study reflects documented knowledge from one way of knowing. It is not intended to describe the 'true' nature of dive fisheries, but provide hints toward this ultimate goal and suggest needs for achieving it. This approach is reasonable, as it can be expected that the gathered information represents the best available scientific knowledge currently accessible to resource managers. Understanding gaps in this information is important for successful future management.

Similarly, because this is a scoping study, the research objectives described above are both targeted and exploratory in nature. The intention is to gather insights on the nature, extent, and sustainability of dive fisheries as presented in the literature. As such, the research objectives described above are approached via systematic, quantitative review and also via inductive, qualitative review. The latter approach allows for themes in the literature to emerge organically (rather than be pre-determined) to both contextualize quantitative descriptions of dive fisheries and accurately reflect the content of the literature. Thus, a mixed-methods approach is intended to provide a well-rounded understanding of the extent and nature of dive fisheries. This approach is especially necessary as collection of quantitative data that could provide a reliable proxy for economic sustainability was deemed outside the scope of this study; however, descriptive and qualitative information gathered can provide insights to observed economic patterns and outcomes in dive fisheries.

This project represents the first attempt to understand and describe the general nature and extent of dive fisheries globally. By shedding light on how dive fishing affects individuals, communities, economies, and resources, this study aims to provide a foundation of knowledge from which further research can be built and sustainable management practices can be developed.

2. METHODS

This study relied on a mixed methods review of peer-reviewed and grey literature to address the above research objectives. The same literature was used for both the quantitative and inductive qualitative review, and both approaches are described here:

2.1 *Article search*

Articles were identified through compiling sources accumulated over several years of dive fishery investigation by the author and two colleagues. To supplement these collections and ensure sufficient capture of the relevant literature, a key term search was performed on five online databases (Google Scholar, PubMed, Rubicon, Novanet, and the Directory of Open Access Journals). Literature databases were selected to identify articles based in a wide range of disciplines (e.g. fishery assessment, fishery management, and anthropological studies). Accessing papers in dive and hyperbaric medicine was a particular focus, because information on diver morbidity and mortality is largely confined to medical literature, which is often excluded from general databases. Key terms were limited to those that specifically mentioned 'fishers,' 'fisheries,' or 'fishing,' and 'dive' or 'diving' (i.e. '~dive AND ~fisher' or '~diving AND ~fishing'). Terms were selected to increase the chances of returning articles related to dive fisheries, while limiting return of articles referencing diving marine animals or interactions between recreational divers and marine life. The title and abstract of the first 100 sources returned from each database search were reviewed and included if they appeared to be referencing dive fisheries and were not already included in the assembled collection.

2.1.1 Inclusion criteria

After generating a list of potential sources, we reviewed them to determine if they met our inclusion criteria. The criteria for inclusion were that the source must (i) explicitly reference use of an underwater breathing apparatus (UBA) to exclude sources discussing breath-hold dive fisheries, (ii) reference a specific fishery with a defined geographical location, even at the country level, and (iii) be available in English.

2.2 *Quantitative review*

Articles were reviewed for specific fishery characteristics to inform our general understanding of the nature of dive fisheries as presented in the scientific literature. Quantitative data were also collected to inform indicators of social and ecological sustainability outcomes within each fishery.

2.2.1 Fishery characterization

Where available, the following fishery characteristics were recorded for each fishery: number of fishers, target species (or the most specific taxonomic group available), UBA type (i.e. SCUBA, hookah/compressor, or hard hat/helmet), location (i.e. country, body of water, and most precise identifiable location mentioned), fishery scale (small-scale or industrial), fishery sector (commercial or subsistence), and fishery status (i.e. was the dive fishery open or closed to fishing at the time of publication).

Collecting quantitative metrics on highly variable fisheries can present a range of challenges. In most cases, characteristics were assigned based on the original author's designation. However, when sufficient information was provided, assignments were made based on common understandings of the collected metrics. Small-scale and industrial fisheries are historically challenging to distinguish between, but designations were made here based on the original source's author or based on commonly accepted SSF characteristics, such as relatively small boats carrying few crew, and harvesting resources in nearshore waters (Table 1). While different countries vary in their definitions of small-scale fisheries, there is a large degree of commonality (Chuenpagdee, Liguori, Palomares, and Pauly, 2006) found disparities but also a large degree of commonality. They note that, while some countries define SSFs by the nature of their activity – e.g. 'traditional' or 'subsistence use' – this was not a common metric. Most SSFs are, in fact, commercial in nature. Boat size (either in total length, engine capacity, or Gross Registered Tonnage (GRT)) was

provided as a key factor in 65% of the characterized SSFs (Chuenpagdee et al., 2006). In contrast, larger vessels that carry more fishers are considered industrial. While characterization of SSFs does not usually include distance of travel, use of boat size, or power as distinguishing features, it is widely recognized that industrial fisheries travel farther from shore, have capacity to stay at sea longer, harvest more per trip, and generally have a different organizational structure and operations than small-scale fisheries.

Table 1. Summary of definitions of small-scale fisheries (Chuenpagdee et al., 2006)

Key features	**Common definition (range)**
Boat size	between 5-7m; less than 10, 12 or 15m (2 to 24m)
Boat GRT	less than 10 GRT (3 to 50 GRT)
Size of engine	less than 60 HP; between 40-75 HP (15 to 400 HP)
Boat type	canoe, dinghy, non-motorized boat, wooden boat, boat with no deck, traditional boat
Gear type	coastal gathering, fishing on foot, beach seine, small ring net, handline, dive, traps
Distance from shore	between 5-9 km; within 13 km; upto 22 km
Water depth	less than 10, 50 or 100m depth
Nature of activity	subsistence, ethnic group, traditional, local, artisanal
Number of crew	2-3; 5-6
Travel time	2-3 hours from landing sites

Fishery sector was assigned following similar methods. Commercial fisheries are defined as those in which catch is primarily sold to a local or foreign market, while subsistence fisheries are defined as those in which the catch is predominantly used for consumption by the fisher, their family, or local community and not for financial profit. This distinction is fraught with ambiguity, however, since fishers often use their catch for a combination of commercial and subsistence; if both activities are noted as substantial, we recorded the fishery as both. Again, the type was assigned based on the original author's designation or made by the author when sufficient information was provided. Fishery status was assumed to be 'open' unless otherwise stated. Recording that a fishery was practiced by an indigenous was only noted if a source explicitly stated as such.

2.2.2 Sustainability indicators

Diving-related morbidity and mortality metrics were recorded for each fishery where available. Unquantified mentions of injury or death as concerns were also documented. Statistics were sorted into commonly reported themes of DON, DCS, DCI, and mortality, as well as an "other" category for statistics that didn't fall under any of the more commonly reported categories. Where possible, reported statistics were standardized to incidence per diver year and incidence levels within each category were compared across fisheries.

Stock status is assigned primarily according to the designation made in the source document. If the original source does not assign a stock status, but provides sufficient information for its designation, stock status is assigned by the author of this study according to the FAO's categories of exploitation. The categories range from 'underexploited,' which reflects an undeveloped or new fisher believed to have a significant potential for expansion in total production, to 'depleted,' in which catches are well below historical levels, irrespective of the amount of fishing effort exerted (FAO, 2011). These categories are based on the stock abundance, not CPUE, so are concerned with total catch, not catch relative to effort. See Appendix G for definitions of all categories of exploitation.

2.2.3 Adaptive capacity indicator

To situate dive fishery characteristics and sustainability outcomes within global socio-political dynamics, country income group was included in the analysis as a rough indicator of adaptive capacity. Country income group was assigned according to the World Bank List of Economies (World Bank, 2017). We then examined emergent patterns in publications by country, publications per fishery, resource status, and levels of morbidity and mortality relative to country income group.

2.3 *Thematic review*

In addition to recording the quantifiable and categorical data described above, we performed an analytic, qualitative review to allow for identification of common themes across publications and fisheries. This portion of the review was inductive in nature, as categories were not pre-determined. Instead, they were emergent, with some categories emerging later in the review. Therefore, some relevant information was potentially missed in sources reviewed prior to the addition of a category. As a new category became relevant, quotes and notes were recorded under the category heading, by publication. As data collection continued, additional categories were added. Trends emerged within certain categories, while other categories ultimately garnered less attention from the reviewed publications. To allow for exploratory examination, categories were created liberally with the understanding that some of them would ultimately only be populated by information from one source, while others might be mentioned more frequently and lead to the identification of themes common throughout the collection of sources. Only the topics that were mentioned in several sources and which rose to the surface are reported here.

3. RESULTS

3.1 *Reviewed sources*

The initial documents identified for review (via database searches and inclusion of the author's previously identified sources) consisted of 202 papers ranging in publication dates from 1978 to 2016. The majority of documents came from the authors' collections of relevant papers (117), followed by searches on Google Scholar (57), Rubicon (14), Pubmed (6), Novanet (6), and the Directory of Open Access Journals (2). Of the originally identified sources, 103 were excluded from the review due to the following reasons: published prior to 2000 (40), does not mention a

specific fishery (14), does not explicitly state that compressed-air dive methods were employed (14), provides information only on free-diving (12), we were unable to access a copy of the complete document (10), we were unable to review the document due to a language barrier (6), and provides information only on recreational diving that did not involve fishing (2).

Ninety-nine (99) documents were determined to fit our criteria for review. The included documents were published between 2000 and 2016 with a peak in publications in 2001 (20), the fewest in 2003 (1), a mean of 5.9 papers per year, and a median of 4.5 papers per year (Fig. 1.1). A workshop held by the Undersea and Hyperbaric Medical Society dedicated to medical issues and treatment in dive fisheries contributed 15 of the 20 publications reviewed from 2001 in the form of conference proceedings. Overall, the number of publications identified stayed consistent and fairly low over the time period analyzed, with only a slight upward trend in annual publications from 2002 to 2015.

The majority of sources reviewed were peer-reviewed publications (50%), followed by conference papers and proceedings (18%), reports (9%), technical and working papers (6%), abstracts (5%), information bulletins (5%), book chapters (4%), and graduate theses (3%). The disciplinary origin of documents varied widely from resource management to dive medicine to anthropological and economic studies of fisheries and fishing communities.

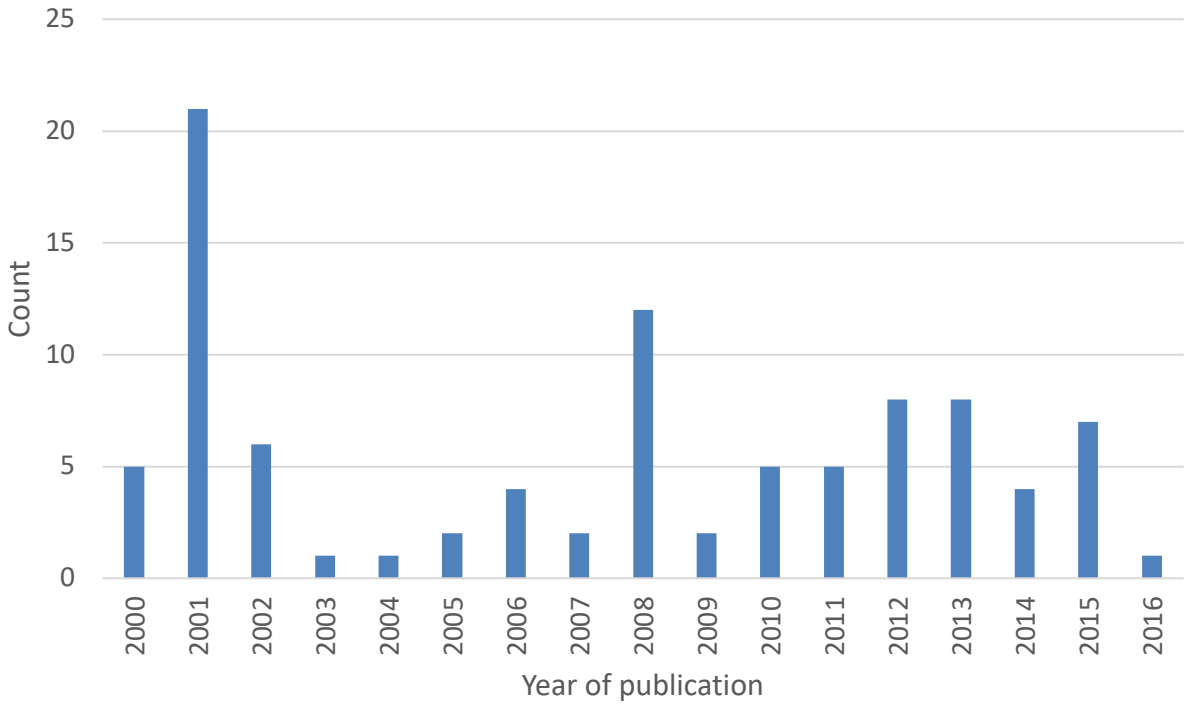

Figure 1. Count of reviewed sources by publication year (2000 – 2016)

3.2 *Dive fishery inventory and characteristics*

3.2.1 Geographic location, size, and status

A total of 118 dive fisheries were identified. Dive fisheries were identified in 60 countries, in both tropical and temperate waters, and on every continent, except Antarctica. The United States accounted for the greatest number of fisheries with 12, followed by Canada (9), Australia (8), and Mexico (6). Papua New Guinea, New Zealand and Chile accounted for three (3) fisheries each. Spain, Grenada, Jamaica, Fiji, Brazil, and Nicaragua each had two (2), while only one (1) fishery was identified in the remaining 37 countries (Fig. 1.2 A). Twenty of the 118 dive fisheries were reported as closed with a ban on UBA. An estimate of fisher numbers was provided for 35 fisheries, with the most fishers reported in the Chile shellfish fishery of 13,199 fishers. The fewest number of fishers – just two – worked in the Oregon, US sea cucumber fishery. There is a mean

of 667 fishers per fishery, however diver numbers varied widely and were not documented for the majority of fisheries.

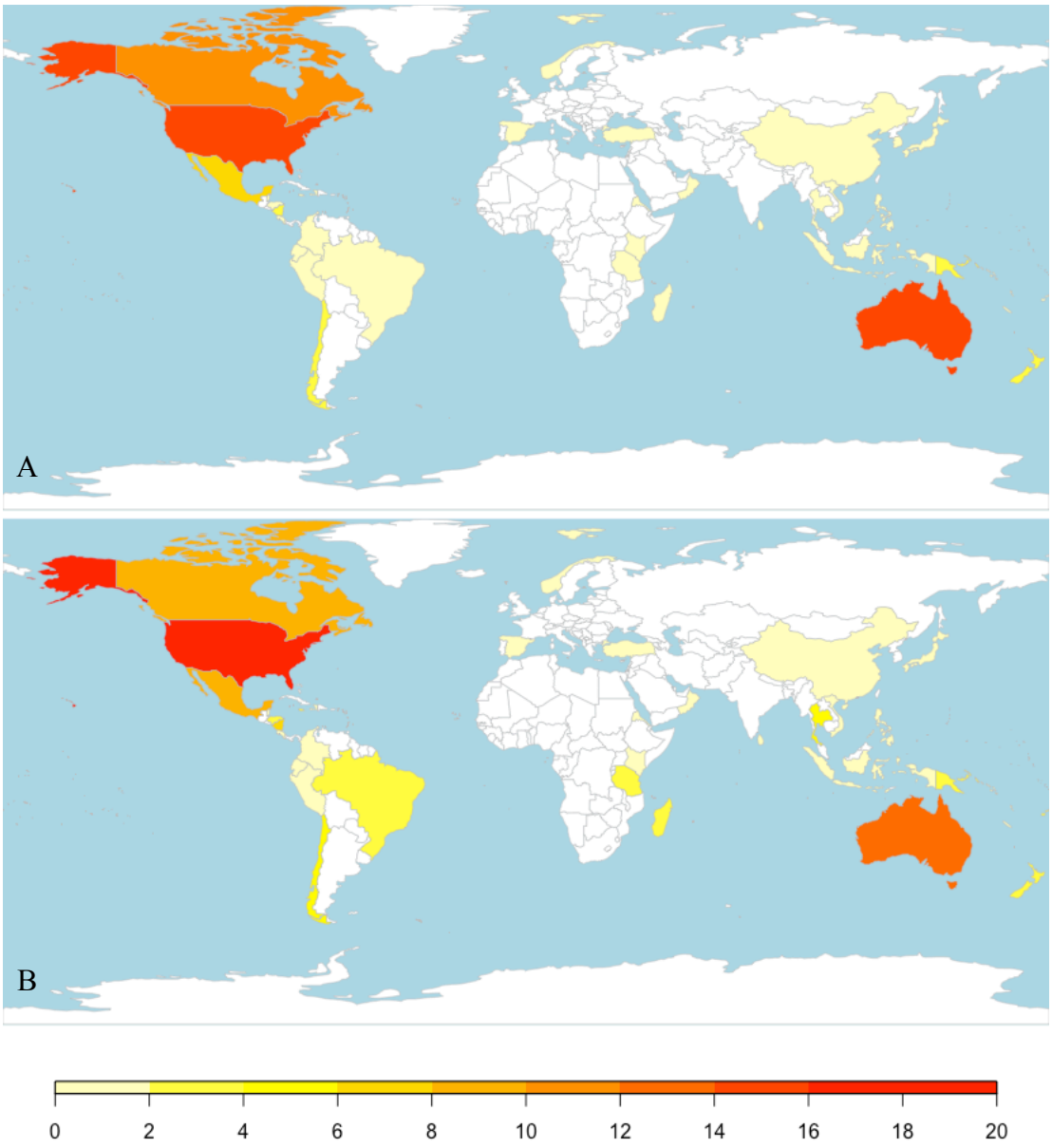

Figure 2. The number of dive fisheries (n = 118) identified in each country (A) and the number of sources (n = 99) that reference dive fisheries in each country (B)

3.2.2 Country income group levels and representation in the literature

The majority of identified dive fisheries were located in high- income countries (47%) as opposed to upper middle-, lower middle-, and low-income countries (31%, 18%, and 4%, respectively). High-income country dive fisheries were also represented in the reviewed literature to a greater extent than those of upper middle-, lower middle-, or low-income countries, accounting for 43% of reviewed sources, with upper middle-, lower middle-, and low-income countries represented in 36%, 16%, and 5%, respectively. Source-to-fishery ratio was fairly consistent across income levels at 1.2, 1.5, 1.3, and 2.0 sources per fishery on average across the respective income groups. This pattern suggests that the relative proportions of dive fisheries identified in different income groups reflect representation in the literature and not actual distribution of dive fisheries, as expected (see Section 4.1).

3.2.3 Fishery scale and sector

The majority of identified dive fisheries were found to be small-scale and commercial in nature. However, there are several exceptions: three are considered industrial (British Columbia abalone, Puerto Cabezas Caribbean spiny lobster, and Seychelles sea cucumber); three are reported as small-scale and industrial (Sri Lanka sea cucumber, Solomon islands sea cucumber (closed), Tuvalu multi-species (closed), and Fiji sea cucumber); and four are indigenous in addition to being small-scale and commercial (Nunavut clam, Metlakatla, Thai Urak Lawoi multi-species, and British Columbia First Nations Geoduck). No fisheries were identified as strictly subsistence, recreational, or traditional. The Alaska abalone was previously harvested in commercial, recreational, and subsistence fisheries, however the commercial fishery is now closed and use of UBA is banned for recreational and subsistence harvest. Most identified dive fisheries are marine wild-capture fisheries, though one freshwater dive fishery (Xingu River ornamental fish) and four

instances of diving in aquaculture operations (Norway fish farms, New Zealand salmon farms, South Australia tuna farms, and dive fishing operations in China) were identified.

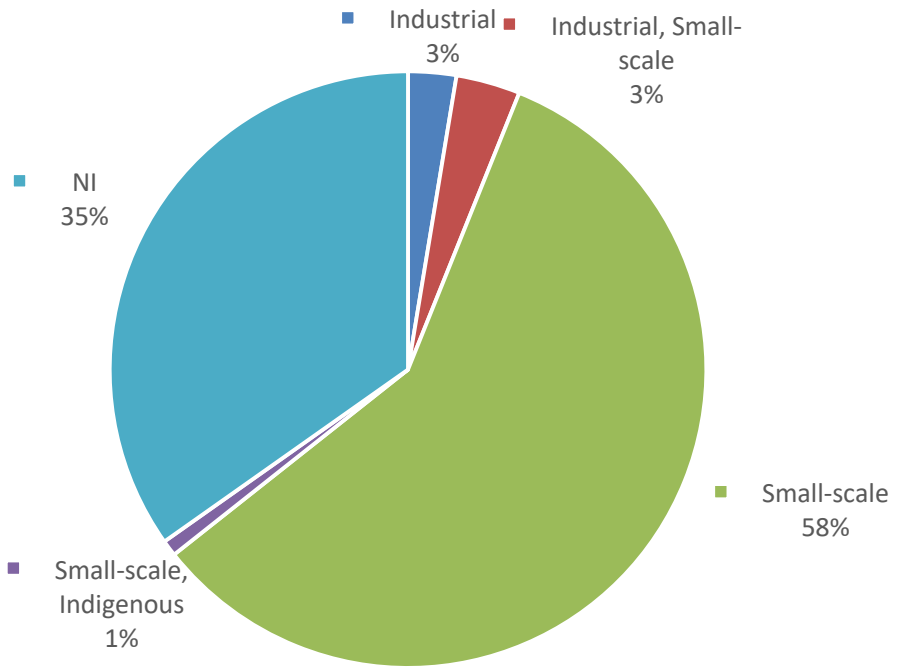

Figure 3. Dive fishery scale (n = 118)

3.2.4 Dive gear used

The type of UBA used in the identified dive fisheries fell into the following categories: unspecified UBA (31%), SCUBA only (25%), hookah only (25%), mixed hookah and SCUBA (8%), mixed SCUBA and breath-hold diving (6%), mixed hookah and breath-hold diving (4%), and a mix of all three (1%) (Fig. 1.4).

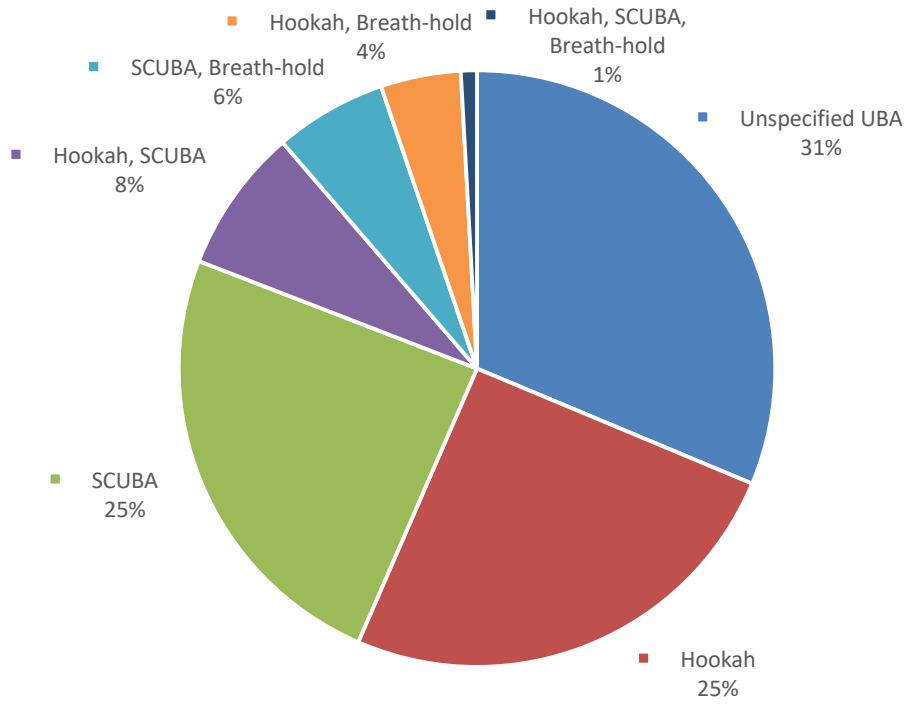

Figure 4. UBA gears used (n = 118)

3.2.5 Species targeted

Target harvest was reported to varying degrees, from not at all to scientific names. Ninety-six different target classifications were reported across 109 fisheries, with 29 fisheries targeting two or more resource types. The majority of fisheries targeted benthic invertebrates (81%). Fisheries also targeted fish (13%), various species in the 'other' category (4%), and, in very few cases, algae (1%) (Fig. 1.5). Species groups in the 'other' category include sponge, crab, coral, unspecified marine species, unspecified aquatic species, and salvage (e.g. for metal from shipwrecks or other manmade objects), each of which was targeted by one fishery.

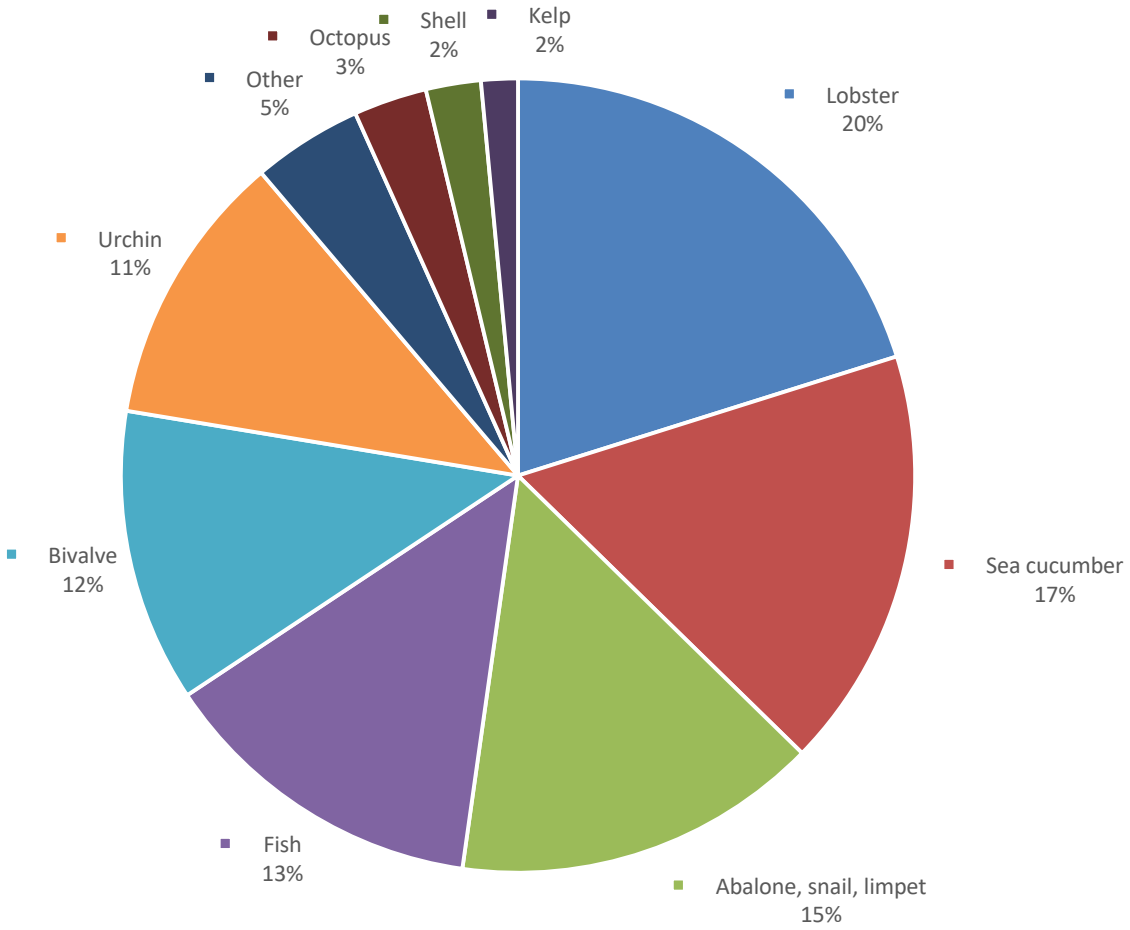

Figure 5. Percentage of fisheries targeting each species group (n = 110)

3.3 *Sustainability outcomes*

3.3.1 Resource status

Resource status was available for just under half (47%) of the identified fisheries. Of the those with stock status information provided, over half (53%) were considered depleted (16%) or over-exploited (37%), more than a quarter (31%) were considered fully-exploited (23%), moderately- to fully-exploited (4%), or fully- to over-exploited (4%), and less than a quarter (16%) were considered moderately exploited (12%) or under-exploited (4%) (Figure 6). While more fisheries

from high income countries are included in our analysis, relative to fisheries in lower middle and low income countries, the latter were reported as having depleted or over-exploited stocks at a substantially higher rate. Resource status of targeted stocks were reported as depleted or over-exploited for only 13% and 23% of fisheries in high and upper middle income countries, respectively, compared with 63% and 60% of fisheries in lower middle and low income countries, respectively. Stock status was reported for fewer high and upper middle income country fisheries proportionally compared with lower middle and low income country fisheries.

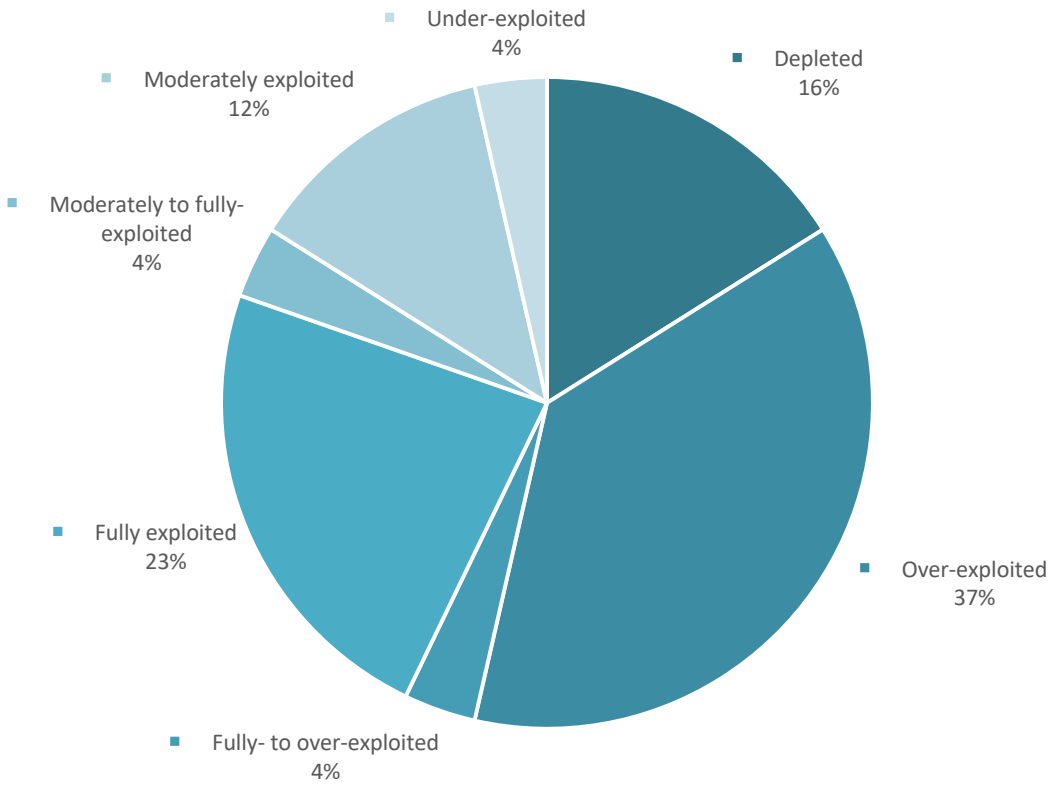

Figure 6. Resource status (n = 56)

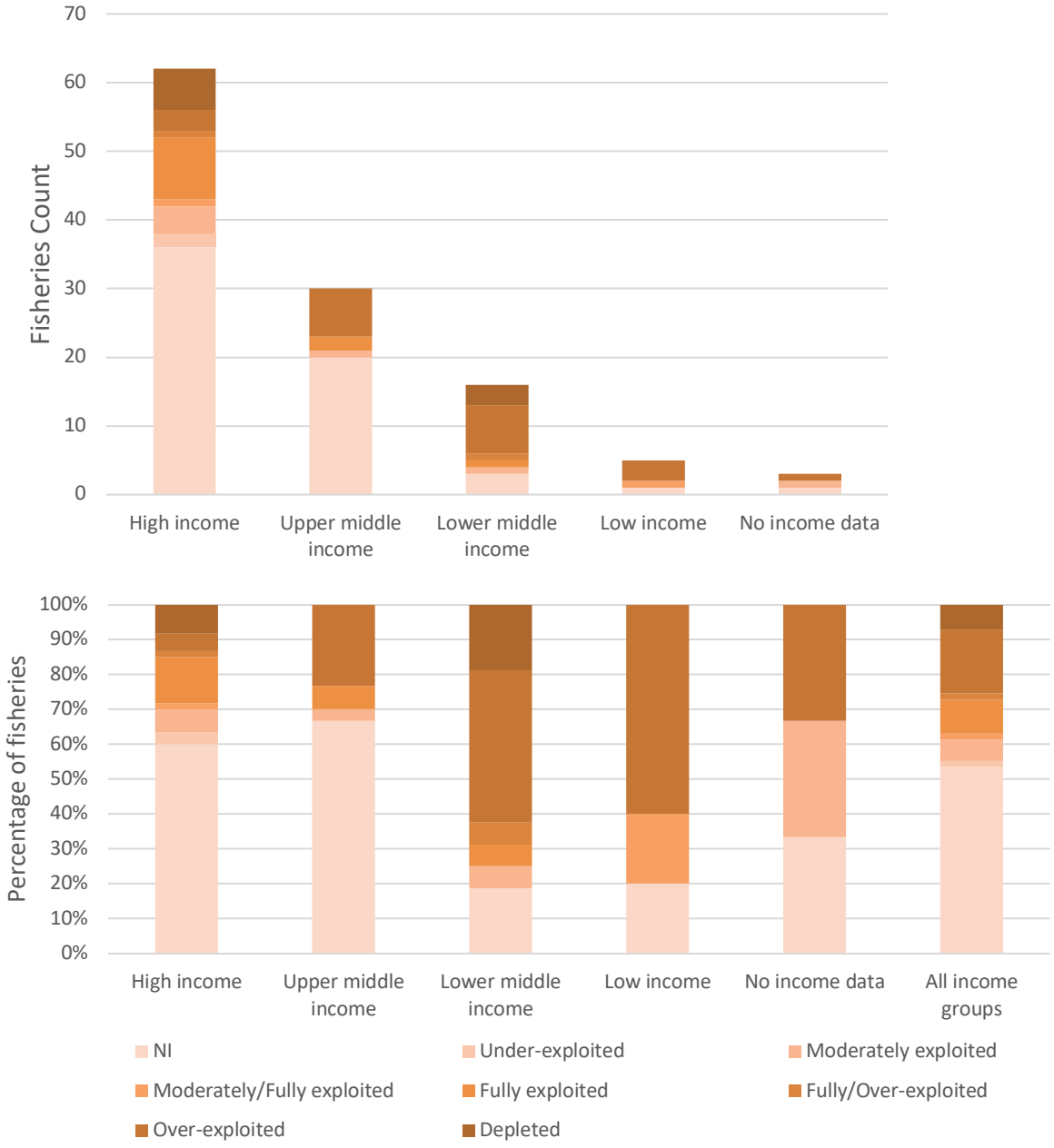

Figure 7. Resource status of fisheries by country income group (n = 118)

3.3.2 Morbidity and mortality rates

Incidence of injury and death was less commonly reported than other fishery characteristics. Quantified measures were reported for only 19 of the 118 identified dive fisheries, and injury and death rates were mentioned as a concern or reported anecdotally in 11 others. Metrics used to

report morbidity and mortality varied substantially. Classification of injury types varied, as did definitions of commonly used terms. In some cases, studies defined injury types in accordance with the hyperbaric medicine literature (e.g. Lepawsky, 2001; Lepawsky, Harbo, & Heizer, 2001), while in others, researchers determined how terms were interpreted locally and based their metrics on that language (e.g. Forman, 2005). While the latter study related local terms to established medical terms, the reporting aligned with local conceptualization of injuries. Further, 'incidence' was variably reported as the rate of a particular injury type per diver year or per dive (e.g. Lepawsky, 2001; Lepawsky, Harbo, & Heizer, 2001). The latter was uncommonly reported, presumably due to needing a comprehensive log of dives completed and injuries and deaths sustained in a given time period to calculate incidence per dive. In several cases, 'incidence' is undefined, lacking specification of the unit of measurement (i.e. per diver year, per dive, or another unit of time) (e.g. Wong, 2001). Incidence is generally reported as per worker year in occupational hazard studies, so that is the assumed unit where not defined otherwise.

The extent of information reported also varied widely by fishery. Several fisheries (e.g. Maine scallop and Western Australia pearl oyster) had only one measurement reported while the most extensively reported fishery (Grenada lobster) had many, six of which are included here. Some studies reported changes in incidence over many years, while others included a single statistic, such as 20 deaths in one year in Marinduque, Philippines (Halim, 2002). Variability in reported metrics limited thorough cross-fishery comparisons of morbidity and mortality, however it was possible to compare across fisheries within defined categories of morbidity and mortality and by standardizing reported metrics where possible.

Reported measures were identified for all of the commonly experienced types of injury with mortality rates most frequently provided (8 fisheries), followed by incidence of DCI (6 fisheries), DCS (6 fisheries), and DON (3 fisheries;

Table 2). DCI incidence was reported for three additional fisheries as a percentage of divers who were presently or had previously experienced DCI symptoms, though the unclear and variable timeframes make the statistics incomparable. Statistics reported for four fisheries were placed in the 'other' category, as they addressed the less commonly reported metrics of unsafe diving practice, spinal injury and joint damage, severe DCS, dive accidents, diving-related medical incident that prevented a subsequent dive, long-term health problems with life-altering consequences, and debilitating injury or death (

Table 2).

Reported morbidity and mortality statistics were ranked from highest to lowest within each category and found to vary widely. Annual incidence of mortality ranged from 5,000 per 100,000 in Marinduque, Philippines to 73.1 per 100,000 in the Maine scallop and sea urchin fisheries. Incidence DCI ranged from 10,000 per 100,000 in the Puerto Cabezas Caribbean spiny lobster and Marinduque, Philippines fisheries to 1,130 per 100,000 in the Maine scallop fishery. A higher DCI incidence of 104% per diver was reported for Miskito Keys, however it's unclear over what time period those DCI incidents occurred. Similarly, a far lower DCI incidence of 0.13% was reported for a Chinese dive fishery, but the time period represented is also unclear. DCS incidence ranged so widely in values and metrics that the reported data cannot be compared across fisheries. Measurements of DCS incidence are qualitatively ranked from perceived high to low levels in

Table 2. Reported levels of morbidity and mortality, but conclusions from this category should be taken with a grain of salt. Similarly, available DON incidence levels are reported but there are too few data for any pattern to emerge.

Inclusion of country income group in the analysis shows a negative correlation between diver risk and country income level. Although there is insufficient data to perform a statistical test of significance, fisheries located in higher-income countries are invariably at the low-risk end of each list, while fisheries located in lower-income countries are invariably at the high-risk end (

Table 2).

Table 2. Reported levels of morbidity and mortality

Fishery ID	Fishery	Mortality	Country income level
F080	Marinduque, Philippines	10 fatalities in 1993; 5% or 5,000 out of 100,000 diver years fatality incidence (SS0056)	Lower middle income
F057	Thai Urak Lawoi multispecies	3.0% or 3,000 per 100,000 diving-related fatality incidence and 6.5% total fatality incidence per diver per year (SS0063)	Upper middle income
F003	Grenada lobster and conch	2.7% or 2,700 per 100,000 diver mortality rate (SS0040)	Upper middle income
F053	Miskito Keys Caribbean spiny lobster	200 fatalities per 100,000 divers per year or 0.2% fatality incidence per diver per year (SS0099)	Lower middle income
F118	Maine green sea urchin	Seven deaths in two years (1992-1993) and three deaths in five years following implementation of mandatory training and regulation. Three deaths in 1992, four deaths and five near-fatal injuries in 1993 prompted legislative action. Only three urchin-related fatalities after mandatory training and regulation: One involved alcohol (1997), one was from a heart attack (1995), and one resulted from improperly diving under ice (1998). Decrease from 0.44% fatality incidence or 440 fatalities per 100,000 diver years during two years before regulations (1992-1993) to 0.33% fatality incidence or 330 fatalities per 100,000 diver years during five years after regulations (1994-1998) (SS0185)	High income
F049	Vietnam sea cucumber (Ninh Van and Ly Son Island)	0.4% or 400 per 100,000 diver years fatality incidence, pre-intervention; <0.1% or <100 per 100,000 diver years fatality incidence, post-intervention (SS0032)	Lower middle income
F064, F118	Maine scallop and sea urchin	0.0731% or 73.1 per 100,000 diver years fatality incidence (SS0192)	High income
F019*	British Columbia commercial geoduck	0.0053% (pre-quota) and 0.0015% (post-quota) fatality incidence per dive (SS0093, SS0186)	High income

* Note that fatality incidence of F019 is measured per dive, rather than per diver year, thus the death rate artificially appears substantially lower than the others and should not be directly compared to them.

Fishery ID	Fishery	DCI Incidence	Country income level
F053	Miskito Keys Caribbean spiny lobster	128 DCI incidents from 123 divers or 104% DCI incidence (SS0099)	Lower middle income
F080	Marinduque, Philippines	20 serious, non-fatal DCI cases in 1993 – 10% incidence or 10,000 DCI events per 100,000 diver years (SS0056)	Lower middle income

F085	Tasmania abalone	1.4% DCI incidence per diver year (SS0022)	High income
F064	Maine scallop	34 divers treated for DCI over 9 years (1989 - 1997) or 1.13% treated DCI incidence (SS0192)	High income
F051*	Chinese dive fishery	5,278 treated DCI cases over 11 years (February 2000 - December 2010); 0.13% DCI incidence per dive (SS0092, originally reported by Liu, Jiang, Li, Liu, & Jiao, 2010 [Article in Chinese])	Upper middle

* Note that DCI incidence of F051 is measured per dive, rather than per diver year, thus the rate artificially appears substantially lower than the others and should not be directly compared to them.

Fishery ID	**Fishery**	**DCI experienced** (as percentage of divers)	**Country income level**
F057	Thai Urak Lawoi multispecies	97.9% of active divers currently experiencing suspected or probable, non-disabling DCI symptoms (SS0063); 60% of current divers classified as suffering from recurring non-disabling decompression illness (SS0063)	Upper middle income
F003	Grenada lobster and conch	81% of divers experienced DCI in their careers (SS0040)	Upper middle income
F118	Maine green sea urchin	78% of surveyed divers reported symptoms compatible with decompression illness, pulmonary over-pressurization, barotrauma, and nitrogen narcosis (SS0185)	High income

Fishery ID	**Fishery**	**DCS statistics**	**Country Income Group**
F049	Vietnam sea cucumber (Ninh Van and Ly Son Island)	All divers present with Type I DCS symptoms (SS0032); Type II DCS experienced at rate of 0.8% or 800 DCS events per 100,000 diver years, pre-intervention, and 0.2% or 200 events per 100,000 diver years, post-intervention (SS0032)	Lower middle income
F105	Puerto Cabezas Caribbean spiny lobster	75-100% incidence 'mild' DCS (SS0015)	Lower middle income
F063	Turkey sponge and shellfish	DCS incidence of 28.5% in 1985, 25.3% in 1990, and 74.5% in 1996 (SS0187)	Upper middle income
F003	Grenada lobster and conch	Eleven incidents of 'bubbles' or 'other symptoms' (represent Type I DCS in local terms) per diver over career (SS0040); Two incidents of 'bends' (represent Type II DCS and AGE in local terms) per diver over career; 63% of divers experienced 'bends' in their careers (SS0040)	Upper middle income
F083	Taiwan dive fishery	DCS incidence up to 72.6% (SS0115)	High income

F065	Western Australia wild pearl oyster	0.01% DCS incidence down from 40% in the 1980s (SS0191)	High income
F019	British Columbia commercial geoduck	0.0093% (pre-quota) and 0.0062% (post-quota) incidence treated DCS per dive (SS0093, SS0186)	High income

* Note that DCS incidence of F019 is measured per dive, rather than per diver year, thus the rate artificially appears substantially lower than the others and should not be directly compared with them.

Fishery ID	Fishery	DON statistics	Country Income Group
F063	Turkey sponge and shellfish	DON incidence was 85.7% in 1985, 52.1% in 1990, and 70.6% in 1996 (SS0187)	Upper middle income
F081	Japan multispecies	28.2% DON incidence (SS0189)	High income
F019	British Columbia commercial geoduck	0.0024% incidence DON per dive between 1978-1989 (most years are pre-quota implementation) (SS0093, SS0186)	High income

* Note that DON incidence of F019 is measured per dive, rather than per diver year, thus the rate artificially appears substantially lower than the others and should not be directly compared to them.

Fishery ID	Fishery	Other statistics
F003	Grenada lobster and conch	26% of divers reported at least one diving-related medical incident that prevented a subsequent dive in their career (SS0040); 50% of divers reported long-term health problems with life-altering consequences (SS0040)
F014, F015	San Felipe and Rio Lagartos multispecies	39% diving accident rate (SS0177); 175 incidents from 1993 to 1996 (SS0177); 209 recorded DCS incidents per year from 2003 to 2012 (SS0064)
F049	Vietnam sea cucumber (Ninh Van and Ly Son Island)	5% incidence of death or injury to the extent that the diver can no longer work in the fishery (pre-intervention) (SS0019)
F057	Thailand Urak Lawoi multispecies	22.7% spinal injury incidence and 30% joint damage incidence (out of 98 examined divers) (SS0063); 0.55% incidence disabling morbidity with 5.21% of active and ex-divers experiencing diving-related disabling injuries in their career (SS0063)

Fishery ID	Fishery	Qualitative reports
F135	Southern Baja scallop	Fatalities reduced after a hyperbaric chamber was installed nearby (SS0188)

F042	Colombia lobster and conch	Diver safety is a concern but no numbers reported (SS0028)
F037	Sri Lankan sea cucumber	Accidents increased as divers need to go deeper, but morbidity and mortality rates are not quantified (SS0134)
F026	Tuvalu multi-species	Deaths led to close of fishery (SS0222, SS0047)
F028	Tonga sea cucumber	Deaths noted, not quantified (SS0222, SS0047)
F038	Eritrea sea cucumber	Decompression accidents occur frequently, including paralysis and death (SS0134)
F082	Fiji sea cucumber	Injuries and death mentioned several times but no rates reported (SS0014, SS0222, SS0024, SS0047)
F024	Scotland king scallop	Scallop divers suffer worse consequences from DCS events than professionally trained sport or amateur divers (SS0182)
F004	Tanzania sea cucumber	Headache and bleeding of nose and ears are common. Light paralysis experienced daily. Several serious cases of paralysis (often with permanent disability) several times a year. Death was not uncommon. (SS0057, SS0058, SS0142)
F075	Indonesia ornamental fish	Paralysis or death suffered by many fishermen from “efforts to pursue valuable fish in deep water.” Ten divers reported to have “died from the bends” over several years in Barrang Lompo of South Sulawesi. Similar cases happen in other parts of Indonesia, but are not accurately reported (SS056).
F094, F105	Corn Islands and Puerto Cabezas Caribbean spiny lobster	1,500 disabled divers on the coast due to the diving industry (Dennis, 2003); Incidents where divers are lost at sea (SS0015)
F101	Western Australia abalone	One diver died after a shark attack in 1998 and one diver died in 1999 from entrapment and running out of air. No DCS reported in the past five years, but “it was as high as 20% in the past, mainly ‘niggles,’ rashes or itches.” Neurological DCS was uncommon and experienced divers (of more than 10 years) often self-treat musculoskeletal DCS with in-water recompression “to the depth of relief then decompression empirically." No reports of DON, but retired divers report shoulder pain. One known case of DON in the past (SS0023)

3.4 *Common themes*

Twenty-four common themes across the literature emerged from the inductive portion of this review. As intended, themes identified earlier on in the review process acquired more records, while fewer records were compiled for those identified later (Figure 8). Themes around fishery

evolution and development were identified as salient early on and were well-represented in the literature. Physical risk and safety-related themes emerged more prominently as the review progressed, though were less-represented in the literature. Themes were organized into common categories post-hoc (Table 3) and patterns that emerged across fisheries are described below.

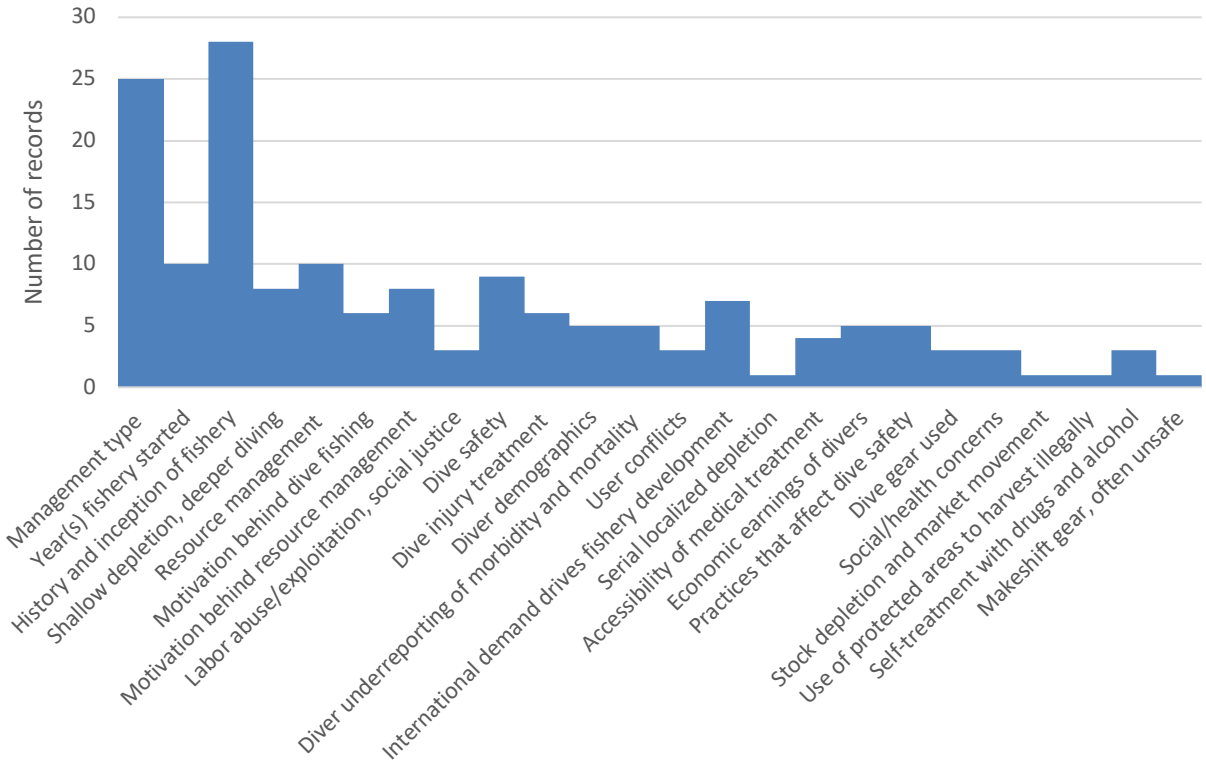

Figure 8. Common themes across fisheries in order of addition and with number of records

Table 3. Common themes across dive fishery literature

Category	**Theme** (order added, number of records)
Fishery development	Year(s) dive fishery started (2, 10)
	History and inception of dive fishery (3, 28)
	Motivation behind dive fishing (6, 6)
	Fishery development driven by international demand (14, 7)

Fishery management	Management type (specific) (1, 25)
	Resource management (general) (5, 10)
	Motivation behind resource management (7, 8)
Gear	Dive gear used (19, 3)
	Makeshift gear, often unsafe (24, 1)
Demographics	Diver demographics (11, 5)
Economic	Economic earnings of divers (17, 5)
Social	Social/health concerns (20, 3)
	Labor abuse/ exploitation/ social justice issues (8, 3)
	User conflicts (13, 3)
Physical risk and safety	Dive safety (9, 9)
	Practices that led to more or less safe diving (18, 5)
	Dive injury treatment (10, 6)
	Accessibility of medical treatment (16, 4)
	Self-treatment with drugs and alcohol (23, 3)
	Diver underreporting of morbidity and mortality (12, 5)
Ecological	Resource depletion in shallow waters leading to deeper and longer diving (4, 8)
	Serial localized depletion (15, 1)
	As stocks get fished out, markets move to new stocks (21, 1)
	Use of protected areas to harvest illegally (22, 1)

3.4.1 Fishery development

Many of the dive fisheries developed in response to similar external factors. Several sources noted that the focal fisheries evolved out of breath-hold dive fisheries, such as the Eritrea and Sri Lanka sea cucumber fisheries (Conand, 2008), the indigenous *bilhaa* divers of Canada (Menzies, 2010), aboriginal pearl oyster divers of Australia (Wong, 2001), and the artisanal Papua New Guinea sea cucumber fishery (Sabetian & Foale, 2006). Other dive fisheries evolved from collection on foot in intertidal zones, such as sea cucumber harvest in the Seychelles (Conand, 2008). In many cases, breath-hold diving had been practiced as early as the 1800s (Marguerite, 2005) and indigenous fishers were diving for resources for centuries prior to adoption of compressed-air diving (e.g. Menzies, 2010; Wong, 2001). Native American divers harvested urchins using breath-hold techniques for millennia prior to introduction of UBA (Butler, 2001).

Economic opportunity and new technology were the primary drivers of dive fishing's development. Many of the fisheries grew rapidly in the later 1900s with expansion driven by non-indigenous groups in response to the introduction of new markets (e.g. Castilla, Gelcich, & Defeo, 2007), increased demand from global markets (e.g. Aumeeruddy & Payet, 2004), higher prices to fishermen (e.g. Menzies, 2010), and increased availability and accessibility of compressed air dive technology (e.g. Rogers-Bennett, Haaker, Huff, & Dayton, 2002; Wong, 2001). In particular, the 1970s saw a substantial increase in dive fishing effort parallel to surges in recreational divers (Rogers-Bennett et al., 2002). The trend of dive fishing expansion continued into the 1990's and 2000's, as SCUBA and hookah was introduced to new areas and foreign demand for the products grew (e.g. Conand, 2008; Purcell, Lovatelli, & Pakoa, 2014).

Both in antiquity and modern times, dive fishery development and expansion was largely driven by Asian markets (e.g. Castilla et al., 2007; Conand, 2008; Fernández, 2008). While some fisheries provided subsistence locally, those that targeted benthic invertebrates like sea urchin and sea cucumber saw both high demand and high prices for their catch in Asian markets where demand had surpassed local supply (ref). In Sri Lanka, for example, although the animals were abundant, they were not harvested until Singapore created demand (Conand, 2008). Similarly, Pacific Islands have exported beche-de-mer, the processed sea cucumber product, to Asian markets intermittently for more than 160 years (Purcell et al., 2014).

The trend of Asian markets catalyzing dive fishery growth appears to continue unabated, with sea cucumber fisheries continuing to increase exploitation in response to Asian demand well into the 2000s (e.g. Eritrea sea cucumber, Conand, 2008). As recently as 2014, researchers note that the few fisheries in the Pacific Islands that have remained subsistence have come under recent pressure to open harvests for export (Purcell et al., 2014). Similarly, Butler et al (2001) describe

how, in 1987, Japanese demand for sea urchin shifted to Maine after the temporary collapse of the U.S. West Coast harvest, creating a new "cash cow" for the east coast state. In this case, legislative actions were able to reign in the booming fishery before collapse, but this was not always the case.

3.4.2 Physical risk and safety

The rapid onset of dive fishing's growth and its financial draw, likely contributed to creation of unsafe work conditions in several ways. There often developed an asymmetry of technology and knowledge of safe diving practices, with dive fishers receiving little or no training (e.g. Jones, Jr., Salbador, Lopez, Ramirez, & Doty, 2001; Ruffez, 2014; Wong, 2001). In many fisheries, fishers do not have access to manufactured gear and instead use dive gear that is makeshift and often minimal, unsafe, or improperly maintained (e.g. Jones, Jr. et al., 2001; Ruffez, 2014; Xu et al., 2012). As a lucrative economic endeavor, pressure to produce for buyers and increase efficiency has resulted in risky diving practices in many cases (Monnereau, 2012; Xu et al., 2012).

With increased pressure to produce, often came over-exploitation and localized depletion, requiring divers to dive deeper or longer or find new fishing grounds to maintain productivity levels. Diving deeper, in turn, tended to lead to increased incidence of injury and death (e.g. Conand, 2008; Halim, 2002; Jones, Jr. et al., 2001). Many of the reports of are staggering. For example, Ruffez (2008) highlights that the 5% morbidity and mortality rates in the sea cucumber fishery in Ly Son Island, Vietnam prior to intervention means that half of the dive fishers would be replaced every 10 years and this statistic is higher in other provinces. Pollard, Lehner, & Heureux (2001) note that the occupational mortality rate of scallop and urchin divers in Maine, U.S.A. is 10 times higher than the state average, despite being one of the lower mortality rates reported across all dive fisheries. And in the Thai Urak Lawoi multispecies dive fishery, almost

all divers active at the time of the study (97.9%) were suffering from suspected or probable non-disabling DCI symptoms (Gold, Geater, et al., 2000).

Insufficient resources for treating injuries is commonly reported. In many cases, medical equipment and treatment facilities, such as onboard oxygen tanks and hyperbaric chambers, are reported as inadequate (e.g. Jones, Jr. et al., 2001; Ruffez, 2014) and use of drugs and alcohol before or after diving to alleviate symptoms is common (e.g. Chin et al., 2015; Fernández, 2008; O. Huchim-Lara et al., 2015; Jones, Jr. et al., 2001; Xu et al., 2012). However, attempts to self-medicate generally have the counter-productive effect of leading to injury accumulation rather than mitigating negative physical impacts (Monnereau, 2012; Xu et al., 2012). Cocaine, for example impairs judgment and affects the cardiovascular system (Dennis, 2003).

Self-medication is further problematic in that it is often employed rather than seeking medical attention, leading to underreported rates of injury and death (e.g. Chin et al., 2015; Huchim-Lara et al., 2015; Jones, Jr., Salbador, Lopez, Ramirez, & Doty, 2001). Under-reporting of injuries occurs for a variety of social, cultural, economic, or personal reasons. For example, Ruffez (2014) reports that an injured diver in Madagascar would not speak to researchers because he was ashamed of what happened to him. Similarly, in Viet Nam, divers are unlikely to report injuries because they believe injuries are a result of destiny (Ruffez, 2008). Under-reporting is particularly common for less severe injuries or ongoing symptoms that may be normalized within the community. According to Butler (2001):

> *While fatalities and near fatalities attracted the most attention, a quiet epidemic of urchin spine injuries arose. Most divers suffered through them; however, a small cadre of divers became patients. (p74)*

In addition, dive injuries and deaths can occur as a result of multiple interrelated factors with similarly complicated symptoms, making them hard to diagnose even if recorded. Blatteau et al. (2016) describe morbidity and mortality in the sea cucumber dive fishery of Ninh Van and Ly Son Island, Vietnam in the following way:

> *Accidents recorded are not always easy to diagnose: in general, they are type 2 decompression accidents (medullary or cerebral accidents), which rapidly disable them and frequently make them paraplegic… Excessive intra-lung pressure accidents have also been recorded when hoses break. Divers must return to the surface with no air. Because they have no fins, the 50 m ascent is exhausting and they stop breathing to give themselves a fair chance, but this entails a major risk of excessive pressure in the lungs. Some divers also die on the bottom, probably because of excessive toxic gas content in the air they breathe. (p43)*

Difficult diagnoses add to the challenges of tracking, recording, and addressing M&M events. Several sources note inaccurate, incomplete, or non-existent records of dive accidents and injury (e.g. Brubakk, 2001; Gold, Geater, et al., 2000; Halim, 2002). Under-reporting and minimal records were commonly reported to hamper efforts to understand hazards and improve safety measures. This lack of information regarding the extent of physical harm contributes to a further challenging management environment.

3.4.3 Fishery management

Despite the strikingly high morbidity and mortality levels in most fisheries and in comparison to other occupations, some fisheries have achieved relatively safer means of operation. In most cases, improved safety outcomes have resulted from changes in regulations or interventions focused on education and training.

Successful efforts to promote safe diving have largely taken place in more capitalized and highly-regulated fisheries. For example, the Nova Scotia sea urchin dive fishery saw only one dive

fatality between 1992 and 2008 (Miller & Nolan, 2008). Similarly, the British Columbia geoduck fishery saw a 66% decrease in fatalities per dive after implementation of catch quotas (Lepawsky, 2001; Lepawsky et al., 2001). And impressively, the Western Australian wild pearl oyster fishery saw what was estimated as a 4000% decrease in DCS incidence after a suite of regulations were implemented, including mandatory annual medical exams (Wong, 2001).

Fisheries in less-capitalized countries have also seen substantial safety improvements as a result of foreign-led interventions. For example, the sea cucumber fisheries in Nanh Van and Ly Son Island, Vietnam saw a 75% reduction in DCI incidence following intervention (Blatteau et al., 2016). However, there was no reporting on other social or economic impacts of interventions and external intervention was noted to be inappropriate in one case (Ruffez, 2008).

Management approaches employed in the identified dive fisheries vary widely. Fisheries employed Territorial User Rights Frameworks (TURFs; Conand, 2008), co-management governance structures (e.g. Carr & Heyman, 2012), combined temporal and spatial closures (e.g. Cudney-Bueno, 2000), limited entry (ref), individual fishing quotas (Hamel & Mercier, 2008), among others. Some fisheries are unregulated and effectively open access (Dunford, Mejia, Salbador, Gerth, & Hampson, 2002). The variety of management strategies employed largely reflect alignment with common practices in fisheries' local or regional area. The disparity highlights that there is no clear strategy that has been adopted for managing dive fisheries specifically.

In several cases, concerns around over-exploitation of stocks and physical harm to divers were addressed with complete or partial bans on dive fishing. Some fisheries closed entirely, including several Pacific Island fisheries, such as the Tuvalu sea cucumber dive fishery (Pakoa & Bertram, 2013), and numerous lobster fisheries in the Caribbean, including Belize, Dominica, St. Lucia, St.

Kitts and Nevis, and Turks and Caicos (CRFM, 2011). Other fisheries have endeavored to shift to other harvest methods, such as the transition toward trapping in Nicaragua's Corn Island spiny lobster fishery (Daw, 2008). However varied the implementation of management approaches or UBA bans, the motivation was consistent across fisheries; regulatory changes were motivated by concerns regarding overexploitation of stocks and fisher safety.

4. DISCUSSION

4.1 *Global extent, underreported, disproportionately studied*

The global extent and distribution of dive fisheries documented in the literature shows that the dive fishing practice is widespread. While 118 dive fisheries operating in 60 countries is already quite substantial, there are several indications that this initial inventory is on the conservative side. Based on this review, it appears that dive fisheries are not comprehensively or equitably treated in the scientific literature. There are several perceived gaps in this initial inventory suggesting it only represents the tip of the iceberg.

First, despite the results of this study, there are many dive fisheries the author knows to exist through first- or second-hand knowledge, but that were not represented in the reviewed literature. In many cases, these fisheries have not been treated in the scientific literature. For example, we are aware of several dive fisheries in disparate locations throughout the Philippines (Bassett pers. comm. and pers. obs.), but only one has been referenced in the reviewed literature. Some of these dive fisheries have been documented in popular media, which was not included in this review, as well as in earlier studies that were excluded from the review based on an inclusion criteria requiring sources to have been published in the year 2000 or later (e.g. Bourke, Verwork, Dawson, & Cross, 1998; Dawson, Bourke, & Cross, 1998; Verwork, Bourke, Dawson, & Cross, 1998).

Second, other dive fisheries may have been documented in scientific literature that was not captured in this literature search. Review and reference mining of the included literature uncovered additional sources that appear to include information about dive fisheries and may identify additional fisheries. These sources were not captured by the search primarily because they do not use terms that identify the fishing method, such as 'dive fishing,' in the title or text. While the studies may address dive fisheries, the fishing method is not the focus and authors do not reference it, thus evading our Boolean search terms.

Third, in addition to the authors knowledge of other dive fisheries, other researchers have previously suggested the existence of large numbers of divers that were not captured in the scientific literature. A study published in 2000 reported personal communications with colleagues who suggested that as many as 33,000 indigenous divers were operating out of the Caribbean, Central America, and South America, possibly 10,000 divers were fishing in the Philippines, and several thousands of indigenous divers were operating out of various coastal sites in Indonesia (Gold, Aiyarak, et al., 2000). While these personal communications should not be disregarded, the quoted numbers have not been substantiated in a systematic way. Similarly, Conand (2008) asserts that upwards of three million fishers rely on sea cucumbers for livelihoods globally, and likely many of these fishers would access sea cucumbers via diving, but how many use UBA versus other methods is unknown. The numbers cited here are much greater than the officially reported counts reported on in this study and, while still deemed insufficiently supported for inclusion in the compiled inventory, they highlight the potential magnitude of the rift between local knowledge of dive fisheries and that within the realm of science and management.

Fourth, in addition to dive fisheries either not being reported in the literature or the relevant literature not being captured in this study, the issue of fishery scale has also depressed and obscured

the total count of dive fisheries. The reviewed sources present fisheries data on a variety of scales, from highly-localized to regional, which cannot be easily or effectively disentangled. In some instances, a dive fishery was reported on a small spatial scale, such as the Oregon sea cucumber fishery which was documented as including two divers and operating out of one town (Hamel & Mercier, 2008). In contrast, some dive fisheries span entire countries, such as the Chilean shellfish fishery, with a reported 13,000 fishers (Andrew et al., 2002; Castilla et al., 2007; Fernández, 2008). Despite the magnitude of difference in their scale, each of these fisheries is counted as one dive fishery.

Fifth, disproportionate treatment of fisheries across income groups means that dive fisheries in lower-income countries have likely been underrepresented in the scientific literature and thus, in this study. Highly-capitalized countries known to have strong resource management programs (i.e. United States, Australia, and Canada) account for, by far, the most dive fisheries identified in this review. The number of fisheries identified per country is highly correlated with the number of sources that address dive fisheries in these countries, suggesting that identified dive fisheries reflect the extent of research performed in these regions more than their true distribution. High income group countries have an average of four sources per country, while the lower three income group countries, each have an average of two sources per country. Studies show that small-scale fisheries are relatively more abundant in mid- and low-income countries than high-income countries (Chuenpagdee & Pauly, 2006), in contrast to the trend identified here.

The assertion that dive fisheries in lower income countries are underrepresented in the scientific literature is further supported by questionably low numbers of dive fisheries in countries likely to have many more. As a poignant example, this review has identified one dive fishery in all of Indonesia (Halim, 2002), a country of 13,466 islands, a coastline of 54,716 km (Central

Intelligence Agency, 2019a), and anecdotally reported to be home to thousands of indigenous dive fishers (Gold, Aiyarak, et al., 2000). In contrast, 17 dive fisheries have been identified in the United States which has a coastline of approximately a third of the size of Indonesia at only 19,422 km (Central Intelligence Agency, 2019b). Greater representation of dive fisheries in high-income countries in the scientific literature suggests that there are likely substantially more dive fisheries in lower income countries that have not been documented in this body of knowledge.

Lastly, in addition to lack of representation of entire dive fisheries, many dive fisheries were relatively less-represented in the reviewed literature. Reviewed sources originated in a variety of disciplines and focal lenses, so information to characterize individual fisheries was largely incomplete within a single source. Dive fisheries referenced by only one paper (68% of identified fisheries) tend to have less-complete and well-rounded information. Again here, dive fisheries discussed in more sources (i.e. those in high-income countries) are represented with greater detail and thus are more represented in this characterization of dive fisheries. For example, in the US dive fisheries, geographic location is specified to the state level or lower and target species are identified, whereas the fishery in Indonesia is only reported to exist, with no additional information provided.

For the reasons above, the inventory of dive fisheries compiled here is suggested to be a conservative estimate of the number of dive fisheries and fishers globally. Review of peer-reviewed and grey literature constrains this study's results to reflect documented scientific knowledge, not the true extent of dive fisheries. However, the perceived systematic biases in identification of dive fisheries suggests that there are potentially many more in operation than have been identified here. If this is indeed the case, dive fishing could be quite widespread and many more people could be involved with the practice than currently acknowledged.

4.2 *Importance for coastal communities*

As a predominantly small-scale harvest method targeting high-value species, dive fishing presents a valuable economic opportunity for coastal communities. Operating almost entirely as commercial fisheries supplying international demand for benthic invertebrates, dive fisheries hold a uniquely lucrative space.

In addition to provision of material assets via income generation, dive fisheries likely provide well-being to local communities in a variety of forms. Small-scale fisheries tend to play important roles in multiple aspects of local life in interconnected ways, thus contributing to social and cultural dimensions of well-being (Béné, 2006). Potential contributions include facilitation of good social relations, promotion of an individual's sense of agency, spirituality, or self-actualization, and provision of social capital in accordance with local values (Weeratunge et al., 2014). These psychological, social, spiritual and cultural dimensions of well-being are more difficult to quantify and less-commonly addressed in studies concerned with resource management or occupational hazards, as predominantly reviewed here. However, a complete understanding of the nature of small-scale fishing livelihoods is essential for development of effective management (Allison, Allison, & Ellis, 2001). A targeted study of the socio-cultural nature of dive fisheries would likely reveal many additional contributions to coastal communities and considerations for social sustainability of the practice.

Due to their highly lucrative nature and almost invariable existence as small-scale fisheries, dive fisheries may play vital roles in well-being provision to local communities. While well-being contributions are needed, a high level of reliance may also translate to increased sensitivity to perturbations of the system. As such, coastal communities involved with and reliant on dive

fisheries are more vulnerable to associated hazards, including effects of physical danger and resource over-exploitation.

4.3 *A dangerous occupation*

Physical safety of divers is a clear undercurrent in the dive fishery literature. Despite morbidity and mortality statistics being relatively few, the combination of quantitative measures and qualitative reports suggest that dive fishing is one of the most dangerous occupations on record. While morbidity and mortality rates vary widely across dive fisheries, almost all of the reported injury and death rates exceed rates reported for other occupations known to be exceptionally dangerous.

Worldwide, fishing is known to be one of the most dangerous peacetime occupations. A recent news article listed the 25 most dangerous occupations in the U.S. based on 2017 data from the U.S. Bureau of Labor Statistics. Aside from fishing, the 24 highest fatality occupations reported have fatality rates between from 8.4 and 87.3 fatalities per 100,000 full-time employees (Sauter & Stockdale, 2019). Firefighters and police are the 24th and 18th most dangerous occupations, respectively, with annual fatality incidences of 8.9 and 12.9 per 100,000 workers. Logging is reported as the second most dangerous occupation, with a fatality rate of 87.3 per 100,000 full-time employees, but fishing tops the list with a fatality incidence of 0.1% or 100 deaths per 100,000 full-time employees.

Fishing is one to two orders of magnitude higher than the other most dangerous occupations and dive fishing is more dangerous still. All but one reported measures of fatality incidence (with comparable units) in dive fisheries surpass the average fatality rate of U.S. fishers by more than 300%. The six fatality rates reported range from <100 to 5,000 fatalities per 100,000 diver years. The U.S. fishery with reported statistics has a fatality rate of 330 per 100,000 diver years, thus is

330% higher than the average fatality rate of U.S. fishers, which is already the most dangerous occupation in the U.S.

While occupational fatality rates are much lower in industrialized countries than less industrialized countries, rates recorded for dive fishing are still much higher than most documented rates. Global annual occupational fatal injury rates are estimated around 14 deaths per 100,000 workers (Takala, 1999). Ahn, Bena, & Bailer (2004) summarize cross-country differences, noting that, "Countries in established market economies average five deaths per 100,000 workers, countries in former socialist economies of Europe, India, and China all reported 11 deaths per 100,000 workers, while other Asian countries and islands average 23 per 100 000 workers." In this authors' comparison of occupational fatality rates of the United States and South Korea, they note that the United States has rates nearly twice as low as South Korea. However, South Korea's most dangerous occupation (mining) has an average annual fatality rate of 161 per 100,000 workers, which is still far lower than several of the rates documented for dive fisheries (Ahn et al., 2004).

While diving is an inherently dangerous activity, dive fishing is also substantially more dangerous than other types of diving. Injury rates in dive fisheries exceed those of recreational, commercial, and scientific diving. The recreational dive fatality rate in the US and Canada is far lower than metrics reported for dive fisheries at 2 per 100,000 divers per year or 0.002% (Divers Alert Network, 2016). Similarly, rate of occurrence of DCI in operational dives varies: approximately 0.095% for commercial divers, 0.03% for US Navy divers, and 0.015% for scientific divers (Vann, 2004). In contrast, the four comparable dive fishery measures of DCI incidence range from 1.13% to 10%, exceeding other diver groups' rates by two to three orders of magnitude.

While dive fishing appears to also be one of, if not the most, dangerous methods of fishing, the data are unclear. In a review of studies of general mortality of fishermen, published rates of mortality in fisheries range from 180 to 570 deaths per 100,000 fishermen year (Matheson et al., 2001; Table 4). Several documented fatality rates in dive fisheries exceed these levels, however, they are in lower-income countries, while the fisheries in the review are all in higher-income countries. Dive fisheries in comparable contexts, also have comparable fatality rates. To determine whether dive fishing is more dangerous than other forms of fishing a targeted study that provides an updated review of fisher mortality across countries, fishing methods, and sectors is needed.

Table 4. Summary of previously published studies of general mortality in fishermen (Matheson et al., 2001)

Year published	*Authors*	*Location*	*Period of data collection*	*No. of subjects*	*Data collection method*	*Average annual mortality rate: cases/1000*
1971	Schilling	UK-wide	1958–1967	208 deaths at sea	Existing data from the Registrar General	1.8–2.8
1969	Moore	Grimsby, UK	1963	14 deaths at sea (population of 2460)	Logbooks on vessels and a medical clinic	5.7
1981	Richardson	Hull, UK	1970–1977	64 deaths at sea	Existing data	–
1985	Reilly	UK	1961–1980	909 deaths at sea	Existing data	2.2
1992	Grainger	Grimsby, UK	1967–1980	33 fishermen and 103 lumpers (all deaths)	Existing data from death certificates	–
1997	Jaremin *et al.*	Poland	1985–1994	148 deaths at sea	Existing data from medical documentation and official reports into specific cases	1.3
1994	Driscoll *et al.*	Australia	1982–1984	47 deaths at sea	Existing data: Coroners' files	–
1993	Schnitzer *et al.*	Alaska, USA	1980–1988	278 deaths at sea	Existing data: death certificates	4.1
1990	Hasselback and Neutal	Nova Scotia, New Brunswick and Prince Edward Island, Canada	1975–1983	1289 deaths (population of 31 415)	Mortality database/register of licensed fishermen	1.4–1.7 (<55 years) 0.6 (>55 years)

Occupational injuries in dive fishing are likely underreported (see Section 3.4.2). While accurate morbidity and mortality statistics are valuable for cross-fishery and cross-occupation comparison, in practice, they are exceedingly challenging to ascertain. Underreporting and incomplete records of dive fishing-related injury and death suggests that the measures compiled

here are on the conservative side. Fisheries in less-capitalized regions are likely to be disproportionately underrepresented in the morbidity and mortality data, because they are generally underrepresented in the literature, and because closely monitored fisheries are more likely to have records of morbidity and mortality. This is particularly true for more severe injuries and fatalities, as more insidious injuries, like those from urchin spines, can more easily go unaddressed (Butler, 2001). However, occupational hazards are thought to be underreported globally (Concha-Barrientos, Nelson, Fingerhut, Driscoll, & Leigh, 2005) so the trends across occupations outlined above may hold true.

Given that the rates of death and injury reported for dive fisheries exceed metrics for other occupations, other diving practices, and possibly other fishing methods, it stands to reason that dive fishing may be one of the most dangerous occupations on record. In fact, Ehrhardt et al (2006) suggests that since rationalization of the Alaskan Bering Sea crab fishery (of "Deadliest Catch" fame) and the resulting improved safety, dive fishing may take the title as the most dangerous occupation in the world. While the relatively few available M&M metrics compiled here cannot confirm Ehrhardt's assertion, they do provide additional support for it.

4.4 *Great risk, great reward*

The characteristics, observed sustainability outcomes, and common themes of dive fisheries illuminated by this study, paint a picture of 'great risk, and great reward.' Considering dive fisheries as social-ecological systems, the combination of high levels of biophysical hazard (physical danger and reduction of stocks) with high levels of social vulnerability (high exposure and sensitivity of coastal communities globally) results in high levels of risk. Risk threatens system sustainability and ongoing provision of inclusive well-being, however, it can be mitigated. Adaptive capacity within social systems reduces vulnerability and can be seen to reduce risk within

several dive fisheries identified in this review, considering that country income group has acted as a very rough and imperfect indicator of adaptive capacity in this study. However, observed trends in sustainability appear to reflect more the capacity to disrupt positive feedback cycles, than simply country income level, as interventions to improve dive safety have been successful in less capitalized countries (see Section 3.4.2). Fisheries in which social organization was sufficient to establish management strategies to address risk within the system, were able to benefit from the 'great rewards' of harvesting high-value species efficiently, selectively, and autonomously.

However, this potential for 'great rewards' may serve to exacerbate the risk inherent to the practice. If not properly managed, this lucrative opportunity can manifest as a poverty trap. Butler (2001) alludes to this pattern when he says, "A lot of fatality are from "inexperienced" divers, who think it's easy and fast money. The money is good, but the work is hard." Resource use activities with qualities seen in dive fisheries – i.e. high potential economic yield for relatively low effort – have been termed 'lootable' and the existence of such sectors has been shown to be destabilizing for states they exist within (Snyder & Bhavnani, 2005).

5. CONCLUSIONS

Dive fisheries pose a sustainable management challenge with striking potential for both great risk and great reward. Governance and management for sustainable dive fisheries is critical for ensuring the well-being of small-scale dive fishers and the communities they support around the world. In light of the practice's potential for providing benefits through highly efficient and selective harvest of high value species and the documented physical risks experienced in practice, dive fisheries have received far less attention from the research community than warranted.

Examples of successful interventions, relatively safe fishing practices, healthy stocks, and productive fisheries show that dive fishing can be a sustainable practice with the ability to benefit coastal communities. Still, the majority of identified dive fisheries are seeing substantial risk to diver well-being and over-exploitation of stocks. With climate and consumption patterns placing greater strains on the ocean's resources and social systems everywhere, developing and implementing sustainable management approaches is ever more critical. While dive fishing is practiced in small pockets along far-off coasts, their ripple effects affect everyone from coastal communities to consumers to fellow citizens

Further research should continue to address dive fisheries as a unique and important marine harvest strategy with particular sustainability considerations. Additions to the inventory could be made through expert survey and analysis of popular media to access fisheries that have received less research attention. Additionally, further examination of the timeline of dive fishery evolution and future progression, as well as assessment of effectiveness of different management strategies are needed.

REFERENCES

Adger, W. N. (2006). Vulnerability. *Global Environmental Change*, *16*(3), 268–281. https://doi.org/10.1016/j.gloenvcha.2006.02.006

Ahn, Y. S., Bena, J. F., & Bailer, A. J. (2004). Comparison of unintentional fatal occupational injuries in the Republic of Korea and the United States. In *Injury Prevention* (Vol. 10, pp. 199–205). https://doi.org/10.1136/ip.2003.004895

Allison, E. H., Allison, E. H., & Ellis, F. (2001). The Livelihoods Approach and Management of Small-Scale Fisheries The livelihoods approach and management of small-scale fisheries. *Marine Policy*, *25*(September), 377–388. https://doi.org/10.1016/S0308-597X(01)00023-9

Andrew, N. L., Agatsuma, Y., Ballesteros, E., Bazhin, a G., Creaser, E. P., Barnes, D. K. a, … Xiaoqi, Z. (2002). Status and management of world sea urchin fisheries. *Oceanography And Marine Biology An Annual Review*. https://doi.org/10.1201/9780203180594.ch7

Arquette, M., Cole, M., Cook, K., LaFrance, B., Peters, M., Ransom, J., … Stairs, A. (2002). Holistic risk-based environmental decision making: a Native perspective. *Environmental Health Perspectives*, *110*(suppl 2), 259–264. https://doi.org/10.1289/ehp.02110s2259

Asche, F., Garlock, T. M., Anderson, J. L., Bush, S. R., Smith, M. D., Anderson, C. M., … Vannuccini, S. (2018). Three pillars of sustainability in fisheries. *Proceedings of the National Academy of Sciences of the United States of America*, *115*(44), 11221–11225. https://doi.org/10.1073/pnas.1807677115

Aumeeruddy, R., & Payet, R. (2004). Management of the Seychelles sea cucumber fishery: status and prospects. In A. Lovatelli, C. Conand, S. Purcell, S. Uthicke, J.-F. Hamel, & A. Mercier (Eds.), *Advances in sea cucumber aquaculture and management. FAO Fisheries Technical Paper 463* (pp. 239–246). Rome.

Bassett, H. R. (2015). Diving in Small-scale and Artisnal Fisheries. In *Undersea and Hyperbaric Medical Society Pacific Chapter Meeting*. Ventura, CA.

Béné, C. (2006). Small-Scale Fisheries : Assessing Their Contribution To Rural Livelihoods in Developing Countries. *FAO Fisheries Circular No. 1008*, 57.

Blatteau, J.-E., Pontier, J.-M., Buzzacott, P., Lambrechts, K., Nguyen, V. M., Cavenel, P., & Ruffez, J. (2016). Prevention and treatment of decompression sickness using training and in-water recompression among fisherman divers in Vietnam. *Injury Prevention : Journal of the International Society for Child and Adolescent Injury Prevention*, *22*(1), 25–32. https://doi.org/10.1136/injuryprev-2014-041464

Bourke, A., Verwork, C., Dawson, R., & Cross, M. (1998). A study of the diving practices and the incidence of decompression sickness in a population of indigenous diving fishermen in the Philippines (Noc Nocan). In *Undersea and Hyperbaric Medical Society, Inc. Annual Scientific Meeting*. UHMS Inc. Retrieved from http://archive.rubicon-

foundation.org/667%0D%0D%0A

Bove, A. (2017). Overview of Diving Injuries. Retrieved March 12, 2017, from http://www.merckmanuals.com/home/injuries-and-poisoning/diving-and-compressed-air-injuries/overview-of-diving-injuries

Breslow, S. J., Allen, M., Holstein, D., Sojka, B., Barnea, R., Basurto, X., … Levin, P. S. (2017). Evaluating indicators of human well-being for ecosystem-based management. *Ecosystem Health and Sustainability*, *3*(12), 1–18. https://doi.org/10.1080/20964129.2017.1411767

Brubakk, A. O. (2001). Diving Activity on Commercial Fish Farms in Norway. In M. Lepawsky & R. M. Wong (Eds.), *Workshop of the Undersea and Hyperbaric Medical Society* (pp. 39–42). Kensington, MD: UHMS Inc.

Butler, W. P. (2001). Urchin Diving in Maine: The urchin diver and urchin spine injuries. In M. Lepawsky & R. M. Wong (Eds.), *Workshop of the Undersea and Hyperbaric Medical Society* (pp. 61–82). Kensington, MD: UHMS Inc.

Buzzacott, P., Denoble, P., Dunford, R., & Vann, R. (2009). Dive problems and risk factors for diving morbidity. *Diving and Hyperbaric Medicine*, *39*(4), 205–209.

Carr, L. M., & Heyman, W. D. (2012). "It's About Seeing What's Actually Out There": Quantifying fishers' ecological knowledge and biases in a small-scale commercial fishery as a path toward co-management. *Ocean and Coastal Management*, *69*, 118–132. https://doi.org/10.1016/j.ocecoaman.2012.07.018

Castilla, J. C., Gelcich, S., & Defeo, O. (2007). Successes, lessons, and projections from experience in marine benthic invertebrate artisanal fisheries in Chile. In T. McClanahan & J. C. Castilla (Eds.), *Fisheries management: progress towards sustainability* (pp. 23–42). Oxford, UK: Blackwell Publishing.

Central Intelligence Agency. (2019a). Indonesia. Retrieved from https://www.cia.gov/library/publications/the-world-factbook/geos/id.html

Central Intelligence Agency. (2019b). United States. Retrieved from https://www.cia.gov/library/publications/the-world-factbook/geos/us.html

Chin, W., Huchim, O., Wegrzyn, G. H., Sprau, S. E., Salas, S., & Markovitz, G. H. (2015). CO and CO 2 analysis in the diving gas of the fishermen of the Yucatan Peninsula. *Undersea and Hyperbaric Medicine*, *42*(4), 297–305.

Chuenpagdee, R., Liguori, L., Palomares, M. L. D., & Pauly, D. (2006). Bottom-Up, Global Estimates of Small-Scale Marine Fisheries Catches. *Fisheries Centre Research Reports*, *14*(8), 105. https://doi.org/10.14288/1.0074761

Chuenpagdee, R., & Pauly, D. (2006). Small is Beautiful? A Database Approach for Global Assessment of Small-Scale Fisheries: Preliminary Results and Hypotheses. *American Fisheries Society Symposium*.

Conand, C. (2008). Population status, fisheries and trade of sea cucumbers in Africa and the Indian Ocean. *Sea Cucumbers. A Global Review of Fisheries and Trade*, 143–193. Retrieved from http://www.vliz.be/imisdocs/publications/147045.pdf

Concha-Barrientos, M., Nelson, D. I., Fingerhut, M., Driscoll, T., & Leigh, J. (2005). The Global Burden Due to Occupational Injury. *American Journal of Industrial Medicine*, (48), 470–481. https://doi.org/10.1002/ajim

CRFM. (2011). Baseline Review of the Status and Management of the Caribbean Spiny Lobster Fisheries in the CARICOM Region. *CRFM Technical & Advisory Document*, *No. 2011/*, 64.

Cudney-Bueno, R. (2000). Management and conservation of benthic resources harvested by small-scale hookah divers in the northern Gulf of California, Mexico: the black murex snail fishery, 177.

DAN. (n.d.). About Divers Alert Network. Retrieved November 11, 2017, from https://www.diversalertnetwork.org/about/

Daw, T. M. (2008). Spatial distribution of effort by artisanal fishers: Exploring economic factors affecting the lobster fisheries of the Corn Islands, Nicaragua. *Fisheries Research*, *90*(1–3), 17–25. https://doi.org/10.1016/j.fishres.2007.09.027

Dawson, R., Bourke, A., & Cross, M. (1998). A survey to quantify the prevalence of aseptic bone necrosis in two populations of diving fishermen in the Philippines. In *Undersea and Hyperbaric Medical Society, Inc. Annual Scientific Meeting*. UHMS Inc. Retrieved from http://archive.rubicon-foundation.org/681

Dembe, A. E. (2001). The social consequences of occupational injuries and illnesses. *American Journal of Industrial Medicine*, *40*(4), 403–417. https://doi.org/10.1002/ajim.1113

Dennis, P. A. (2003). Cocaine in Miskitu Villages. *Ethnology*, *42*(2), 161–172.

Divers Alert Network. (2016). *DAN Annual Diving Report 2016 Edition: A report on 2014 data on diving fatalities, injuries, and incidents [Internet]*. (P. Buzzacott, Ed.). Durham, NC. Retrieved from https://www.ncbi.nlm.nih.gov/books/NBK424397/

Dunford, R. G., Mejia, E. B., Salbador, G. W., Gerth, W. a, & Hampson, N. B. (2002). Diving methods and decompression sickness incidence of Miskito Indian underwater harvesters. *Undersea & Hyperbaric Medicine : Journal of the Undersea and Hyperbaric Medical Society, Inc*, *29*(2), 74–85.

FAO. (2011). *Review of the state of world marine fishery resources*. *FAO Fisheries and Aquaculture Technical Paper* (Vol. No. 569). Rome. Retrieved from ftp://ftp.fao.org/docrep/fao/007/y5852e/y5852e00.pdf

Fernández, G. G. (2008). Chapter 4: Industrial and artisanal fishing landing in Chile. In *From Seascapes of Extinction to Seascapes of Confidence, Territorial use rights in fisheries in Chile: El Quisco and Puerto Oscuro* (pp. 70–81). Co-Action Publishing.

https://doi.org/10.3402/GALLARDO.V0I0.37

Forman, S. A. (2005). *Decompression illness among the indigenous fishing population of Grenadian waters: assessing the prevalence, perceptions and burden of disease*. St. George's University.

Garrett, M. T. (1999). Undesrstanding the "Medicine" of Native American Traditional Values: An Integrative Review. *Counseling and Values*, *43*(2), 84–98. https://doi.org/10.1002/j.2161-007X.1999.tb00131.x

Gold, D., Aiyarak, S., Wongcharoenyong, S., Geater, A., Juengprasert, W., & Gerth, W. A. (2000). The Indigenous Fisherman Divers of Thailand: Diving practices. *International Journal of Occupational Safety and Ergonomics*, *6*(1), 89–112. https://doi.org/10.1080/10803548.2000.11076446

Gold, D., Geater, A., Aiyarak, S., Wongcharoenyong, S., Juengprasert, W., Johnson, M., & Skinner, P. (2000). The Indigenous Fisherman Divers of Thailand : Diving-Related Mortality and Morbidity. *International Journal of Occupational Safety and Ergonomics*, *6*(2), 147–167. https://doi.org/10.1080/10803548.2000.11076449

Govender, R. (2013). *Small but Mighty: A global reconsideration of small-scale fisheries*. The University of British Columbia.

Halim, A. (2002). Adoption of cyanide fishing practice in Indonesia. *Ocean and Coastal Management*, *45*(4–5), 313–323. https://doi.org/10.1016/S0964-5691(02)00061-3

Hamel, J., & Mercier, A. (2008). Population status , fisheries and trade of sea cucumbers in temperate areas of the Northern Hemisphere. *FAO Fisheries and Aquaculture Technical Paper*, (516), 257–291.

Harris, S. G., & Harper, B. L. (1997). A Native American Exposure Scenario. *Risk Analysis*, *17*(6), 789–795. https://doi.org/10.1111/j.1539-6924.1997.tb01284.x

Harthorn, B. H., & Oaks, L. (Eds.). (2003). *Risk, culture, and health inequality: Shifting perceptions of danger and blame*. Westport, CT, USA: Praeger.

Hodal, K., Kelly, C., & Lawrence, F. (2014, June 10). Revealed: Asian slave labour producing prawns for supermarkets in US, UK. *The Guardian*.

Huchim-Lara, O., Salas, S., Chin, W., Montero, J., & Fraga, J. (2015). Diving behavior and fishing performance: The case of lobster artisanal fishermen of the Yucatan coast, Mexico. *Undersea & Hyperbaric Medical Society, Inc.*, *42*(4), 285–296.

Huchim-Lara, O, Chin, W., Salas, S., Markovitz, G., Marcinkevicius, M., Sprau, S., & Fraga, J. (2013). Diving Behavior in Artisnal Fishermen of the Yucatan Peninsula. *Journal of the Undersea and Hyperbaric Medical Society, Inc.* Retrieved from http://archive.rubicon-foundation.org/10860

Huchim-Lara, Oswaldo, Fraga, J., & Salas, S. (2012). Fishermen social and cultural behavior associated to decompression sickness in lobster fisheries from the eastern coast of Yucatan. In *Proceedings of the 64th Gulf and Caribbean Fisheries Institute* (pp. 142–146).

ILO. (2000). *International Hazard Datasheets on Occupation - Indigenous Fisherman Diver*. Retrieved from http://www.ilo.org/wcmsp5/groups/public/---ed_protect/---protrav/---safework/documents/publication/wcms_186122.pdf

Jacquet, J., & Pauly, D. (2008). Funding priorities: Big barriers to small-scale fisheries. *Conservation Biology*, *22*(4), 832–835. https://doi.org/10.1111/j.1523-1739.2008.00978.x

Jones, Jr., J. P., Salbador, G. W., Lopez, F., Ramirez, S., & Doty, S. B. (2001). High-risk diving and dysbaric osteonecrosis. In M. Lepawsky & R. M. Wong (Eds.), *Workshop of the Undersea and Hyperbaric Medical Society* (pp. 103–110). Kensington, MD: UHMS Inc.

Lenihan, H. S., & Peterson, C. H. (2004). Conserving oyster reef habitat by switching from dredging and tonging to diver-harvesting. *Fishery Bulletin*, *102*(2), 298–305.

Lepawsky, M. (2001). British Columbia Emerald Sea Commercial Diving Geoduck Harvesters. In M. Lepawsky & R. M. Wong (Eds.), *Workshop of the Undersea and Hyperbaric Medical Society* (pp. 83–98). Kensington, MD: UHMS Inc.

Lepawsky, M., Harbo, R., & Heizer, S. (2001). The Incidence of Decompression Illness in British Columbia Geoduck Divers during the First 25 Years of the Fishery. *Undersea & Hyperbaric Medicine Journal*. Retrieved from http://dspace.rubicon-foundation.org:8080/xmlui/handle/123456789/926

Liu, Y., Jiang, S., Li, Z., Liu, S., & Jiao, X. (2010). An epidemiological study on acute decompression sickness of marine product-fishing workers in Dalian region. *Chinese Journal of Industrial Medicine*, (23), 52–54.

Lupton, D. (Ed.). (1999). *Risk and sociocultural theory: new directions and perspectives*. Cambridge, UK: University Press.

Matheson, C., Morrison, S., Murphy, E., Lawrie, T., Ritchie, L., & Bond, C. (2001). The health of fishermen in the catching sector of the fishing industry: A gap analysis. *Occupational Medicine*, *51*(5), 305–311. https://doi.org/10.1093/occmed/51.5.305

Matson, P., Clark, W. C., & Andersson, K. (2016). *Pursuing Sustainability: A guide to the science and practice*. Princeton University Press.

Mayfield, S., Chick, R. C., Carlson, I. J., & Ward, T. M. (2011). Invertebrate dive fisheries can be sustainable: forty years of production from a greenlip abalone fishery off southern Australia. *Reviews in Fisheries Science*, *19*(3), 216–230. https://doi.org/10.1080/10641262.2011.585431

Mendoza, M., & Mason, M. (2016, September 8). Hawaiian seafood caught by foreign crews confined on boats. *Associated Press*.

Menzies, C. R. (2010). Dm sibilhaa'nm da laxyuubm Gitxaała: Picking Abalone in Gitxaała Territory. *Human Organization*, *69*(3), 213–220. https://doi.org/10.17730/humo.69.3.g68p1g7k40153010

Millennium Ecosystem Assessment. (2003). *Ecosystems and Human Well-being: A Framework for Assessment*. Washington, D.C.: Island Press. Retrieved from https://www.millenniumassessment.org/documents/document.48.aspx.pdf

Millennium Ecosystem Assessment. (2005). *Ecosystems and Human Well-being: Synthesis*. Washington, D.C.: Island Press. Retrieved from https://www.millenniumassessment.org/documents/document.356.aspx.pdf

Miller, R. J., & Nolan, S. C. (2008). Management Methods for a Sea Urchin Dive Fishery with Individual Fishing Zones. *Journal of Shellfish Research*, *27*(4), 929–938. https://doi.org/10.2983/0730-8000(2008)27[929:MMFASU]2.0.CO;2

Monnereau, I. (2012). *The red gold rush: the impact of governance styles on value chains and the well-being of lobster fisheries in the wider Caribbean*. Amsterdam Institute for Social Science Research.

Murphy, D. (2018). *Hidden chains: Rights Abuses and Forced Labor in Thailand's Fishing Industry*.

Nelkin, D. (2003). Foreword: The social meanings of risk. In B. H. Harthorn & L. Oaks (Eds.), *Risk, culture and health inequality: Shifting perceptions of danger and blame* (pp. vii–xiii). Wesport, CT: Praeger.

Orensanz, J. M., Parma, A. M., Jerez, G., Barahona, N., Montecinos, M., & Elias, I. (2005). What Are the Key Elements for the Sustainability of " S-Fisheries " ? Insights From South America. *Bulletin of Marine Science*, *76*(2), 527–556.

Pakoa, K., & Bertram, I. (2013). Management state of Pacific sea cucumber fisheries. *SPC Beche-de-Mer Information Bulletin*, (33), 49–52.

Pollard, A. A., Lehner, C. E., & Heureux, C. E. (2001). Profiles of Maine Scallop and Urchin Diving Accidents Treated 1989 to 1997. In M. Lepawsky & R. M. Wong (Eds.), *Workshop of the Undersea and Hyperbaric Medical Society* (pp. 157–160). Kensington, MD: UHMS Inc.

Purcell, S. W., Lovatelli, A., & Pakoa, K. (2014). Constraints and solutions for managing Pacific Island sea cucumber fisheries with an ecosystem approach. *Marine Policy*, *45*, 240–250. https://doi.org/10.1016/j.marpol.2013.11.005

Rogers-Bennett, L., Haaker, P. L., Huff, T. O., & Dayton, P. K. (2002). Estimating Baseline Abundances of Abalone in California for Restoration. *CalCOFI Report*, *43*, 97–111.

Ruffez, J. (2008). Diving for holothurians in Vietnam : A human and environmental disaster. *SPC Beche-de-Mer Information Bulletin*, (28), 42–45.

Ruffez, J. (2014). In Madagascar, sea cucumber harvesting still kills compressor divers. *SPC Beche-de-Mer Information Bulletin*, *34*, 56–57.

Rumble, J., & Hebert, K. (2011). *Report to the Board of Fisheries, miscellaneous dive fisheries. Alaska Department of Fish and Game, Fishery Management Report No 11-59*. Anchorage. Retrieved from http://www.adfg.alaska.gov/FedAidPDFs/FMR14-46.pdf

Sabetian, a., & Foale, S. (2006). Evolution of the artisanal fisher: Case studies from the Solomon Islands and Papua New Guinea. *SPC Traditional Marine Resource Management and Knowledge Information Bulletin*, *20*(December), 8. Retrieved from internal-pdf:/Sabetian & Foale 2006.pdf

Sauter, M. B., & Stockdale, C. (2019, January 8). The most dangerous jobs in the US include electricians, firefighters and police officers. *USA Today*.

Schulte, P. A. (2005). Characterizing the burden of occupational injury and disease. *Journal of Occupational and Environmental Medicine*, *47*(6), 607–622. https://doi.org/10.1097/01.jom.0000165086.25595.9d

Sen, A. (1999). *Development as Freedom*. Oxford: Oxford University Press.

Snyder, R., & Bhavnani, R. (2005). Diamonds, blood, and taxes: A revenue-centered framework for explaining political order. *Journal of Conflict Resolution*, *49*(4), 563–597. https://doi.org/10.1177/0022002705277796

Takala, J. (1999). Global estimates of fatal occupational accidents. *Epidemiology*, *10*(5), 640–646. https://doi.org/10.1016/j.ssci.2005.08.017

Teh, L. S. L., Teh, L. S. L., & Sumaila, U. R. (2013). A Global Estimate of the Number of Coral Reef Fishers. *PLoS ONE*, *8*(6), 65397. https://doi.org/10.1371/journal.pone.0065397

Thomson, D. (1980). Conflict within the fishing industry. *ICLARM*, 2. Retrieved from https://hdl.handle.net/20.500.12348/3672

Vann, R. D. (2004). Mechanisms and risks of decompression. In AA Bove (Ed.), *Bove and Davis' diving medicine* (4th ed.). Philadelphia, PA: Saunders.

Verwork, C., Bourke, A., Dawson, R., & Cross, M. (1998). A study of the diving practices and the indicence of decompression sickness in a population of indigenous hookah diving fishermen in the Philippines. (i: Madridejos). In *Undersea and Hyperbaric Medical Society, Inc. Annual Scientific Meeting*. UHMS Inc. Retrieved from http://archive.rubicon-foundation.org/666

Walker, B., & Salt, D. (2012). *Resilience Practice: Building capacity to absorb disturbance and maintain function*. Washington, D.C.: Island Press.

Weeratunge, N., Béné, C., Siriwardane, R., Charles, A., Johnson, D., Allison, E. H., … Badjeck, M. C. (2014). Small-scale fisheries through the wellbeing lens. *Fish and Fisheries*, *15*(2),

255–279. https://doi.org/10.1111/faf.12016

Wolfley, J. (1998). Ecological risk assessment and management: Their failure to value indigenous traditional ecological knowledge and protect tribal homelands. *American Indian Culture and Research Journal*, *22*(2), 151–169.

Wong, R. M. (2001). Development of Pearl Diving Profiles of Western Australia. In M. Lepawsky & R. M. Wong (Eds.), *Workshop of the Undersea and Hyperbaric Medical Society* (pp. 139–142). Kensington, MD: UHMS Inc.

Woodhead, A. J., Abernethy, K. E., Szaboova, L., & Turner, R. A. (2018). Health in fishing communities: A global perspective. *Fish and Fisheries*, *19*(5), 839–852. https://doi.org/10.1111/faf.12295

World Bank. (2017). List of Economies [Data file]. Retrieved from https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups

Xu, W., Liu, W., Huang, G., Zou, Z., Cai, Z., & Xu, W. (2012). Decompression illness: Clinical aspects of 5,278 consecutive cases treated in a single hyperbaric unit. *PLoS ONE*, *7*(11), 171. https://doi.org/10.1371/journal.pone.0050079

APPENDIX A. LIST OF ABBREVIATIONS

AGE	Arterial gas embolism
CADF	Compressed-air dive fishery
CGE	Cerebral gas embolism
CPUE	Catch per unit effort
DCI	Decompression illness (DCS and AGE)
DCS	Decompression sickness
DON	Dysbaric osteonecrosis
fsw	Feet sea water
POPS	Pulmonary overpressure syndrome
SCUBA	Self-Contained Underwater Breathing Apparatus
SSF	Small-scale fishery
SSFs	Small-scale fisheries

APPENDIX B. REVIEWED SOURCES

Source ID	Reviewed sources	Fisheries included	Type	Search
SS0173	Aburto, J., Gallardo, G., Stotz, W., Cerda, C., Mondaca-Schachermayer, C., & Vera, K. (2013). Territorial user rights for artisanal fisheries in Chile–intended and unintended outcomes. Ocean & Coastal Management, 71, 284-295.	F084	Journal article	Google Scholar
SS0179	Acott, C. J. (2001). Tuna Farm Divers of South Australia. In M. Lepawsky & R. Wong (Eds.), Workshop of the Undersea and Hyperbaric Medical Society (pp. 31-34). Kensington, MD: UHMS Inc.	F058	Conference proceedings (UHMS workshop)	Collection
SS0007	Allen, D. W. (2013). The Fishers of the Pedro Bank, Jamaica: Through the Lens of Their Livelihoods. *Global Journal of Human-Social Science Research*, 13(7).	F083	Journal article	Collection
SS0207	Andrew, N. L., Agatsuma, Y., Ballesteros, E., Bazhin, A., Creaser, E., Barnes, D., ... & Einarsson, S. (2003). Status and management of world sea urchin fisheries. Oceanography and Marine Biology-An Annual Review, 40, 343-425.	F062, F095, F118, F124	Book	Google Scholar
SS0031	Barratt, D. M., & Van Meter, K. (2004). Decompression Sickness in Miskito Indian Lobster Divers: Review of 229 Cases. *Aviation Space and Environmental Medicine*, *75*(4 SEC. I), 350–353.	F053	Journal article	Collection
SS0027	Basurto, X. (2006). Commercial diving and the Callo de Hacha fishery in Seri territory. Journal of the Southwest, 48(2), 189-209.	F002	Journal article	Collection
SS0155	Basurto, X. (2008). Biological and ecological mechanisms supporting marine self-governance: The Seri Callo de Hacha fishery. Ecology and Society, 13(2), 20.	F002	Journal article	Directory of Open Access Journals
SS0032	Blatteau, J. E., Pontier, J. M., Buzzacott, P., Lambrechts, K., Cavenel, P., & Ruffez, J. (2015). Prevention and treatment of decompression sickness using training and in-water recompression among fisherman divers in Vietnam. Injury prevention. doi: 10.1136/injuryprev-2014-041464	F049	Journal article	Collection

SS0181	Brubakk, A. O. (2001). Diving Activity on Commercial Fish Farms in Norway. In M. Lepawsky & R. Wong (Eds.), Workshop of the Undersea and Hyperbaric Medical Society (pp. 39-42). Kensington, MD: UHMS Inc.	F096	Conference proceedings (UHMS workshop)	Collection
SS0077	Bruckner, A. W. (2005). The recent status of sea cucumber fisheries in the continental United States of America. SPC Beche-de-mer Information Bulletin, 22, 39-46.	F090, F091, F092, F093	Information bulletin	Google Scholar
SS0079	Burch, P., Mayfield, S., Stobart, B., Chick, R. C., & McGarvey, R. (2011). Estimating species-specific catch rates in a mixed-species dive fishery. Journal of Shellfish Research, 30(2), 425-436.	F086	Journal article	Google Scholar
SS0185	Butler, W. P. (2001). Urchin Diving in Maine: The Urchin Diver and Urchin Spine Injuries. In M. Lepawsky & R. Wong (Eds.), Workshop of the Undersea and Hyperbaric Medical Society (pp. 61-82). Kensington, MD: UHMS Inc.	F062, F118	Conference proceedings (UHMS workshop)	Collection
SS0123	Carr, L. M., & Heyman, W. D. (2012). "It's About Seeing What's Actually Out There": Quantifying fishers' ecological knowledge and biases in a small-scale commercial fishery as a path toward co-management. Ocean & coastal management, 69, 118-132.	F074	Journal article	Collection
SS0204	Castilla, J. C., Gelcich, S., & Defeo, O. (2007). Successes, lessons, and projections from experience in marine benthic invertebrate artisanal fisheries in Chile. In T. McClanahan & J. C. Castilla (Eds.), Fisheries management: progress towards sustainability, (23-42). Oxford, UK: Blackwell Publishing.	F095, F041	Book chapter	Google Scholar
SS0096	Chao, C., & Chang, L. (2000). Diving patterns and decompression sickness in Taiwanese diving fishermen. *Journal of the Undersea and Hyperbaric Medical Society, Inc.*	F083	Conference proceedings (UHMS workshop)	Rubicon Research Repository
SS0208	Chin, W., Huchim, O., Wegrzyn, G. H., Sprau, S. E., Salas, S., & Markovitz, G. H. (2015). CO and CO2 analysis in the diving gas of the fishermen of the Yucatan Peninsula. Undersea & hyperbaric medicine: journal of the Undersea and Hyperbaric Medical Society, Inc, 42(4), 297.	F015	Journal article	Pubmed
SS0216	Chuenpagdee, R., & Jentoft, S. (2007). Step zero for fisheries co-management: what precedes implementation. Marine policy, 31(6), 657-668.	F013	Journal article	Google Scholar
SS0187	CimSit, M. (2001). Dysbaric Osteonecrosis in Turkish Sponge and Shellfish Divers. In M. Lepawsky & R. Wong (Eds.), Workshop of the Undersea and Hyperbaric Medical Society (pp. 99-102). Kensington, MD: UHMS Inc.	F063	Conference proceedings (UHMS workshop)	Collection

SS0134	Conand, C. (2008). Population status, fisheries and trade of sea cucumbers in Africa and the Indian Ocean. FAO Fisheries and Aquaculture Technical Paper.	F007, F008, F009, F036, F037, F038, F039, F040	FAO Technical Paper	Collection
SS0009	CRFM Secretariat. (2011). Baseline review of the status and management of the Caribbean spiny lobster fisheries in the CARICOM region. (CRFM Technical & Advisory Document Number 2011/5). Belize: CRFM.	F003, F067, F108, F109, F110, F111, F112, F113, F114	Report	Collection
SS0145	Cudney-Bueno, R. (2000). Management and conservation of benthic resources harvested by small-scale hookah divers in the northern Gulf of California, Mexico: the black murex snail fishery.	F079	Thesis	Collection
SS0111	Daw, T. M. (2008). Spatial distribution of effort by artisanal fishers: Exploring economic factors affecting the lobster fisheries of the Corn Islands, Nicaragua. Fisheries Research, 90(1), 17-25.	F094	Journal article	Google Scholar
SS0103	Denoble, P.J., Sanchez, C.A., Fostervold, A., Haukenes, O.M., Brubakk, A.O., & Gerth, W.A. (2001). Diving Patterns in Lobster Fishermen of Isla Mujeres, Mexico. Undersea and Hyperbaric Medicine Journal.	F056	Abstract	Rubicon Research Repository
SS0176	Dunford, R. G., Salbador, G. W., Mejia, E. B., & Hampson, N. B. (2001). Dive Profiles and Results of Treatment. In M. Lepawsky & R. Wong (Eds.), Workshop of the Undersea and Hyperbaric Medical Society (pp. 11-16). Kensington, MD: UHMS Inc.	F053	Conference proceedings (UHMS workshop)	Collection
SS0057	Eriksson, B. H., de la Torre-Castro, M., Eklöf, J., & Jiddawi, N. (2010). Resource degradation of the sea cucumber fishery in Zanzibar, Tanzania: a need for management reform. Aquatic Living Resources, 23(4), 387-398.	F004	Journal article	Collection
SS0058	Eriksson, H., De La Torre-castro, M., & Olsson, P. (2012). Mobility, expansion and management of a multi-species scuba diving fishery in East Africa. PLOS one, 7(4), e35504.	F004	Journal article	Collection
SS0142	Eriksson, H., de la Torre-Castro, M., Purcell, S. W., & Olsson, P. (2015). Lessons for resource conservation from two contrasting small-scale fisheries.Ambio, 44(3), 204-213.	F004	Journal article	Collection
SS0183	Farm, Jr., F. P., Hayashi, E. M., & Beckman, E. L. (2001). Diving and Decompression Sickness Treament Practices Among Hawaii's Diving Fishermen. In M. Lepawsky & R. Wong (Eds.), Workshop of the Undersea and Hyperbaric Medical Society (pp. 49-58). Kensington, MD: UHMS Inc.	F060	Conference proceedings (UHMS workshop)	Collection

SS0114	Featherstone, M., & Rogers, J. (2008). The evolution of co-management in the British Columbia red sea urchin fishery. In Townsend, R. E., Shotton, R., & Uchida, H. (Eds.). Case studies in fisheries self-governance No. 504. (pp383-407). Rome: Food & Agriculture Organization.	F016	Report	Google Scholar
SS0108	Fernández-Boán, M., Freire, J., Parma, A. M., Fernández, L., & Orensanz, J. M. (2013). Monitoring the fishing process in the sea urchin diving fishery of Galicia. ICES Journal of Marine Science: Journal du Conseil, fss207.	F073	Journal article	Collection
SS0054	Fernández, G. G. (2008). Chapter 4: Industrial and artisanal fishing landing in Chile. In From Seascapes of Extinction to Seascapes of Confidence, Territorial use rights in fisheries in Chile: El Quisco and Puerto Oscuro (pp. 70–81). Co-Action Publishing. https://doi.org/10.3402/GALLARDO.V0I0.37	F041	Book Chapter	Collection
SS0013	Fisheries and Oceans. (2012). Pacific Region Exploratory Fishery Guidelines: Octopus by Dive. Canada: Fisheries and Oceans.	F045	Report	Collection
SS0040	Forman, S. (2005). Decompression illness among the indigenous fishing population of Grenadian waters: assessing the prevalence, perceptions and burden of disease. (Unpublished Masters Dissertation). St. George's University, Grenada, West Indies.	F003	Thesis	Collection
SS0132	Gelcich, S., Kaiser, M. J., Castilla, J. C., & Edwards-Jones, G. (2008). Engagement in co-management of marine benthic resources influences environmental perceptions of artisanal fishers. Environmental Conservation,35(01), 36-45.	F041	Journal article	Collection
SS0178	Gold, D. (2001). Indigenous Fishermen Divers of Thailand: Harvester-Gatherers of the Andaman Sea. In M. Lepawsky & R. Wong (Eds.), Workshop of the Undersea and Hyperbaric Medical Society (pp. 25-30). Kensington, MD: UHMS Inc.	F057	Conference proceedings (UHMS workshop)	Collection
SS0062	Gold, D., Aiyarak, S., Wongcharoenyong, S., Geater, A., Juengprasert, W., & Gerth, W. A. (2000b). The Indigenous Fisherman Divers of Thailand: Diving Practices. International Journal of Occupational Safety and Ergonomics, 6(1), 89-112. doi:10.1080/10803548.2000.11076446	F057	Journal article	Collection
SS0233	Gold, D., Geater, A., Aiyarak, S., Wongcharoenyong, S., Juengprasert, W., Chuchaisangrat, B., & Samakkaran, A. (2000c). The indigenous fisherman divers of Thailand: Strengthening knowledge through education and information. Journal of safety research, 31(3), 159-168.	F057	Journal Article	Collection

SS0063	Gold, D., Geater, A., Aiyarak, S., Wongcharoenyong, S., Juengprasert, W., Johnson, M., & Skinner, P. (2000a). The indigenous fisherman divers of Thailand: diving-related mortality and morbidity. International Journal of Occupational Safety and Ergonomics, 6(2), 147-167.	F057	Journal article	Collection
SS0133	Haddon, M., Mayfield, S., Helidoniotis, F., Chick, R. and C. Mundy (2013) Identification and Evaluation of Performance Indicators for Abalone Fisheries. FRDC Final Report 2007/020. CSIRO, Hobart. 297 p. [129 Figures; 44 Tables]	F005, F099, F100, F101, F085, F086	Consultancy Report	Collection
SS0056	Halim, A. (2002). Adoption of cyanide fishing practice in Indonesia. Ocean & Coastal Management, 45(4), 313-323.	F075, F080	Journal article	Collection
SS0197	Hamel, J. F., & Mercier, A. (2008). Population status, fisheries and trade of sea cucumbers in temperate areas of the Northern Hemisphere. FAO Fisheries and Aquaculture Technical Paper.	F018, F090, F091, F092, F093	Technical paper	Google Scholar
SS0184	Hattori, T. (2001). Diving Techniques of the Central Coast Abalone Divers. In M. Lepawsky & R. Wong (Eds.), Workshop of the Undersea and Hyperbaric Medical Society (pp. 59-60). Kensington, MD: UHMS Inc.	F061	Conference proceedings (UHMS workshop)	Collection
SS0097	Huchim-Lara, O., Salas, S., Chin, W., Montero, J., & Fraga, J. (2015). Diving Behavior and Fishing Performance: the Case of Lobster Artisanal Fishermen of the Yucatan Coast, Mexico. Undersea and Hyperbaric Medicine Journal, 42(4), 285-296.	F014,F015	Abstract	Rubicon Research Repository
SS0064	Huchim-Lara, O., Salas, S., Chin, W., Montero, J., Fraga, J., Huchim, O., ... & Weaver, L. K. (2015). Diving behavior and fishing performance: the case of lobster artisanal fishermen of the Yucatan coast, Mexico. Strategies, 27, 28.	F057, F113, F013, F011, F012	Journal article	Collection
SS0149	Jalali, M. A., Ierodiaconou, D., Gorfine, H., Monk, J., & Rattray, A. (2015). Exploring spatiotemporal trends in commercial fishing effort of an abalone fishing zone: a GIS-based hotspot model. PloS one, 10(5), e0122995.	F005	Journal article	Novanet
SS0188a	Jones, Jr., J. P., Salbador, G. W., Lopez, F., Ramirez, S., & Doty, S. B. (2001). High-Risk Diving and Dysbaric Osteonecrosis. In M. Lepawsky & R. Wong (Eds.), Workshop of the Undersea and Hyperbaric Medical Society (pp. 103-110). Kensington, MD: UHMS Inc.	F053, F135	Conference proceedings (UHMS workshop)	Collection
SS0014	Jupiter, S.D., Saladrau, W., & Vave, R. (2013). Assessment of sea cucumber fisheries through targeted surveys of Lau Province, Fiji. Wildlife Conservation Society/University of the South Pacific/Fiji Department of Fisheries/Khaled bin Sultan Living Oceans Foundation, Suva, Fiji, 22 pp.	F082	Report	Collection

SS0210	Karpov, K., Haaker, P., Taniguchi, I., & Rogers-Bennett, L. (2000). Serial depletion and the collapse of the California abalone (Haliotis spp.) fishery. Canadian Special Publication of Fisheries and Aquatic Sciences, 11-24.	F061	Journal article	Google Scholar
SS0189	Kawashima, M., Tamura, H., Takao, K., Yoshida, K., Kitano, M., Mano, Y., Lehner, C., & Taya, Y. (2001). Diving Profile and Dysbaric OsteonecrosisIn M. Lepawsky & R. Wong (Eds.), Workshop of the Undersea and Hyperbaric Medical Society (pp. 111-124). Kensington, MD: UHMS Inc.	F055	Conference proceedings (UHMS workshop)	Collection
SS0215	Khan, A. (2006). Sustainability challenges in the geoduck clam fishery of British Columbia: policy perspectives. Coastal Management, 34(4), 443-453.	F019	Journal article	Google Scholar
SS0190	Lehner, C. E. & Pollard, A. A. (2001). Maine Scallop Divers: Decompression Sickness and the Prevalence of Dysbaric Osteonecrosis. In M. Lepawsky & R. Wong (Eds.), Workshop of the Undersea and Hyperbaric Medical Society (pp. 129-138). Kensington, MD: UHMS Inc.	F064	Conference proceedings (UHMS workshop)	Collection
SS0186	Lepawsky, M. (2001). British Columbia Emerald Sea Commercial Diving Geoduck Harvesters. In M. Lepawsky & R. Wong (Eds.), Workshop of the Undersea and Hyperbaric Medical Society (pp. 83-98). Kensington, MD: UHMS Inc.	F019	Conference proceedings (UHMS workshop)	Collection
SS0093	Lepawsky, M., Harbo, R.M., & Heizer, S. (2001). The Incidence of Decompression Illness in British Columbia Geoduck Divers during the First 25 Years of the Fishery. Undersea and Hyperbaric Medicine Journal.	F019	Abstract	Rubicon Research Repository
SS0224	Levine, A., and S. Allen. (2009). American Samoa as a fishing community. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-PIFSC-19, 74 p.	F034	Technical paper	Collection
SS0094	Long, R.J., Haddock, N., Leask, P.A., Dear, G., & Moon, R.E. (2002). Prevalence of Decompression Sickness among Southeast Alaska Harvest Divers. Undersea and Hyperbaric Medicine Journal.	F054	Abstract	Rubicon Research Repository
SS0052	Lovell, T., & Hallgrímsson, J. H. (2012). *Towards a management plan for Antigua and Barbuda's queen conch fishery: a co-management approach*. United Nations University Fisheries Training Programme, Reykjavik, Iceland.	F044	Report	Collection
SS0113	Mayfield, S., Chick, R. C., Carlson, I. J., & Ward, T. M. (2011). Invertebrate dive fisheries can be sustainable: forty years of production from a greenlip abalone fishery off Southern Australia. Reviews in Fisheries Science, 19(3), 216-230.	F086	Journal article	Google Scholar

SS0051	McConney, P. (2003). Grenada case study: The lobster fishery at Sateurs.Caribbean Coastal Co-management Project. Caribbean Conservation Association, Barbados. 60pp.	F003	Report	Collection
SS0099	Mejia, E., Nochetto, M., Bird, N., Ranapurwala, S., & Denoble, P.J. (2011). A Case Series of Decompression Illness in Miskito Fishermen Divers Treated in 2010 at Clinica La Benedicion. Undersea and Hyperbaric Medicine Journal.	F053	Abstract	Rubicon Research Repository
SS0171	Meltzoff, S. K., Lichtensztajn, Y. G., & Stotz, W. (2002). Competing visions for marine tenure and co-management: genesis of a marine management area system in Chile. Coastal Management, 30(1), 85-99.	F041	Journal article	Google Scholar
SS0199	Menzies, C. (2010). Dm sibilhaa'nm da laxyuubm Gitxaała: picking abalone in Gitxaała territory. Human Organization, 69(3), 213-220.	F087	Journal article	Google Scholar
SS0160	Mesquita, E. M. C., & Isaac-Nahum, V. J. (2015). Traditional knowledge and artisanal fishing technology on the Xingu River in Pará, Brazil. Brazilian Journal of Biology, 75(3), 138-157.	F043	Journal article	Collection
SS0050	Miller, R. J. (2008). A sea urchin dive fishery managed by exclusive fishing areas. FAO FISHERIES TECHNICAL PAPER, 504, 77.	F077	FAO Technical Paper	Collection
SS0003	Ministry of Primary Industries. (2013a). Use of underwater breathing apparatus (UBA) in selected shellfish fisheries (MPI Discussion Paper No: 2013/08). Wellington, NZ: Crown Copyright.	F035, F036, F037, F038, F039, F040	Report	Collection
SS0180	Mitchell, S. J. & Murphy, B. D. P. (2001). Salmon-Farm Divers at Stewart Island, New Zealand: From the Ridiculous to the Sublime. In M. Lepawsky & R. Wong (Eds.), Workshop of the Undersea and Hyperbaric Medical Society (pp. 35-38). Kensington, MD: UHMS Inc.	F059	Conference proceedings (UHMS workshop)	Collection
SS0049	Mohammed, E. & Lindop, A. (2015). Grenada: Reconstructed Fisheries Catches, 1950-2010. Fisheries Centre Working Paper #2015-40, University of British Columbia, Vancouver, 27 p.	F003	Working paper	Collection
SS0015	Monnereau, I. (2012). The red gold rush: The impact of governance styles on value chains and the well-being of lobster fishers in the Wider Caribbean. (Doctoral dissertation). Retrieved from UvA-DARE.	F104, F105, F106	Thesis	Collection
SS0016	Monnereau, I., & Pollnac, R. (2012). Which fishers are satisfied in the Caribbean? A comparative analysis of job satisfaction among Caribbean lobster fishers. Social indicators research, 109(1), 95-118.	F104, F105	Journal article	Collection

SS0060	Morris, R. A., Kingston, J., & Arnason, R. (2010). A bioeconomic analysis of the Jamaican industrial Spiny lobster (panulirus argus) fishery. United Nations University: Fisheries Training Programme, Reykjavik.	F104	Journal article	Collection
SS0212	Mundy, C. N. (2012). Using GPS technology to improve fishery-dependent data collection in abalone fisheries.	F085	Journal article	Google Scholar
SS0046	Nayar, R., Davidson-hunt, I., Mcconney, P., & Davy, B. (2008). Divers and Networks in the Sea Egg Fishery in Grenada Buzos y Redes Comerciales en la Pesca del Huevo Marino de Grenada. *Human Ecology*.	F052	Conference proceedings (GCFI)	Collection
SS0214	O'Regan, S. M. (2015). Harvesters' perspectives on the management of British Columbia's giant red sea cucumber fishery. Marine Policy, 51(1), 103-110.	F016, F017, F018, F019	Journal article	Google Scholar
SS0047	Pakoa, K., & Bertram, I. (2013). Management state of Pacific sea cucumber fisheries. SPC Beche-de-mer Information Bulletin, 33, 49-52.	F028, F026, F082, F022, F023, F021, F025, F027, F032, F033	Information bulletin	Collection
SS0146	Perry, R. I., Ommer, R. E., Allison, E. H., Badjeck, M. C., Barange, M., Hamilton, L., ... & Sumaila, U. R. (2010). Interactions between changes in marine ecosystems and human communities. Marine Ecosystems and Global Change. Oxford University Press, Oxford, 221-252.	F115	Book chapter	Collection
SS0116	Perry, R. I., Zhang, Z., & Harbo, R. (2002). Development of the green sea urchin (Strongylocentrotus droebachiensis) fishery in British Columbia, Canada—back from the brink using a precautionary framework. Fisheries Research, 55(1), 253-266.	F016	Journal article	Google Scholar
SS0192	Pollard, A. A., Lehner, C. E., & Heureux, C. E. L. (2001). Profiles of Maine Scallop and Urchin Diving Accidents Treated 1989 to 1997. In M. Lepawsky & R. Wong (Eds.), Workshop of the Undersea and Hyperbaric Medical Society (pp. 157-160). Kensington, MD: UHMS Inc.	F064, F118	Conference proceedings (UHMS workshop)	Collection
SS0028	Prada, M., Castro, E. R., Grandas, Y., & Connolly, E. (2006). Effects of divers fishing in the San Andres Archipelago: Considerations towards fisheries management and conservation. GCFI Proceedings, 57, 905-916.	F042	Conference paper	Collection
SS0222	Purcell, S. W., Lovatelli, A., & Pakoa, K. (2014). Constraints and solutions for managing Pacific Island sea cucumber fisheries with an ecosystem approach. Marine Policy, 45, 240-250.	F026, F028, F022, F032, F082, F033, F023, F025, F021, F029, F030, F027, F031	Journal article	Google Scholar

SS0162	Rogers-Bennett, L., Haaker, P. L., Huff, T. O., & Dayton, P. K. (2002). Estimating baseline abundances of abalone in California for restoration. Reports of California Cooperative Oceanic Fisheries Investigations, 43, 97-111.	F061	Report	Google Scholar
SS0182	Ross, J. A. S. & Stephenson, R. N. (2001). Patterns of Diving in Sports Divers Commercial Divers and Scallop Divers in Scotland Presenting with Decompression Illness. In M. Lepawsky & R. Wong (Eds.), Workshop of the Undersea and Hyperbaric Medical Society (pp. 43-48). Kensington, MD: UHMS Inc.	F024	Conference proceedings (UHMS workshop)	Collection
SS0019	Ruffez, J. (2008). Diving for holothurians in Vietnam: A human and environmental disaster. Secretariat of the Pacific Community Beche de Mer Information Bulletin, 28, 42-45.	F049	Information bulletin	Collection
SS0020	Ruffez, J. (2014). In Madagascar, sea cucumber harvesting still kills compressor divers. SPC Beche-de-mer Information Bulletin, 34, 56-57.	F020	Information bulletin	Collection
SS0115	Rumble, J., & Hebert, K. (2011). *Report to the Board of Fisheries, miscellaneous dive fisheries. Alaska Department of Fish and Game, Fishery Management Report No 11-59*. Anchorage. Retrieved from http://www.adfg.alaska.gov/FedAidPDFs/FMR14-46.pdf	F133, F134	Report	Google Scholar
SS0005	Sabetian, A., & Foale, S. (2006). Evolution of the artisanal fisher: Case studies from Solomon Islands and Papua New Guinea. *Traditional Marine Resource Management and Knowledge Information Bulletin*, 20, 3-10.	F102, F103	Information bulletin	Collection
SS0177	Sanchez, E. C. & Paredes, H. (2001). Diving-Related Accidents in Commercial Sea Harvesters of the State of Yucatan, Mexico. In M. Lepawsky & R. Wong (Eds.), Workshop of the Undersea and Hyperbaric Medical Society (pp. 17-24). Kensington, MD: UHMS Inc.	F014, F015	Conference proceedings (UHMS workshop)	Collection
SS0152	Sanderson, J. C., Ling, S. D., Dominguez, J. G., & Johnson, C. R. (2016). Limited effectiveness of divers to mitigate 'barrens' formation by culling sea urchins while fishing for abalone. Marine and Freshwater Research, 67(1), 84-95.	F005	Journal article	Novanet
SS0075	Schroeter, S. C., Reed, D. C., Kushner, D. J., Estes, J. A., & Ono, D. S. (2001). The use of marine reserves in evaluating the dive fishery for the warty sea cucumber (Parastichopus parvimensis) in California, USA. Canadian Journal of Fisheries and Aquatic Sciences, 58(9), 1773-1781.	F093	Journal article	Google Scholar
SS0022	Smart, D. (2010). Health risk management in the Tasmanian abalone diving industry. Diving and Hyperbaric Medicine, (40)2, 83-87.	F085	Journal article	Collection

SS0088	Smart, D.R., Van den Broek, C., Nishi, R., Cooper, P.D., & Eastman, D. (2014). Field Validation of Tasmania's Aquaculture Industry Bounce-diving Schedules Using Doppler Analysis of Decompression Stress. Journal of the South Pacific Underwater Medicine Society, 44(3), 124-136.	F050	Journal article	Collection
SS0114	Sosa-Cordero, E., Liceaga-Correa, M.L.A., & Seijo, J. C. (2008). The Punta Allen lobster fishery: current status and recent trends. In Townsend, R. E., Shotton, R., & Uchida, H. (Eds.). Case studies in fisheries self-governance No. 504. (pp149-162). Rome: Food & Agriculture Organization.	F116	Report	Google Scholar
SS0025	Stevenson, T. C., Tissot, B. N., & Dierking, J. (2011). Fisher behaviour influences catch productivity and selectivity in West Hawaii's aquarium fishery. ICES Journal of Marine Science: Journal du Conseil, 68(5), 813-822.	F076	Journal article	Collection
SS0023	Wong, R. M. (2001). Abalone diving in Western Australia diving practices in 1999. South Pacific Underwater Medicine Society (SPUMS) Journal, 31(3), 131-135.	F097, F098, F099, F100, F101, F065, F050, F085, F086	Conference paper	Collection
SS0191	Wong, R. M. (2001). Development of Pearl Diving Profiles of Western Australia. In M. Lepawsky & R. Wong (Eds.), Workshop of the Undersea and Hyperbaric Medical Society (pp. 139-142). Kensington, MD: UHMS Inc.	F065	Conference proceedings (UHMS workshop)	Collection
SS0092	Xu, W., Liu, W., Huang, G., Zou, Z., Cai, Z., & Xu, W. (2012). Decompression Illness: Clinical Aspects of 5278 Cases Treated in a Single Hyperbaric Unit. PLoS One, 7(11).	F051	Journal article	Collection
SS0114	Yandle, T. (2008). Rock lobster management in New Zealand: the development of devolved governance. In Townsend, R. E., Shotton, R., & Uchida, H. (Eds.). Case studies in fisheries self-governance No. 504. (pp291-306). Rome: Food & Agriculture Organization.	F117	Report	Google Scholar
SS0119	Ye, Y., & Dennis, D. (2009). Assessing the impacts of trawling breeding lobsters (Panulirus ornatus) on the catch of the Torres Strait lobster fishery shared between Australia and Papua New Guinea. New Zealand Journal of Marine and Freshwater Research, 43(1), 419-428.	F088, F089	Journal article	Google Scholar

APPENDIX C. EXCLUDED SOURCES

Excluded sources	Reason for exclusion
Buga, B., & Vuki, V. (2012). The people of the artificial island of Foueda, Lau Lagoon, Malaita, Solomon Islands: Traditional fishing methods, fisheries management and the roles of men and women in fishing. SPC Women in Fisheries Information Bulletin 22:42-44.	Breath-hold diving only
Ministry of Primary Industries. (2013b). Use of underwater breathing apparatus (UBA) in selected shellfish fisheries (MPI Regulatory Impact Statement). Wellington, NZ: Crown Copyright.	Breath-hold diving only
Smart, D. R., & McCartney, P. (1990). High risk diving. Tasmania's aquaculture industry. *SPUMS Journal*, 20(3), 159-165.	Pre-2000
FAO. (2000). Safety in Small-Scale Fisheries: What is to be done? Proceedings of the 2000 IFISH Conference. Woodshole, MA: Woodshole Institute of Oceanography.	No specific dive fishery
St. Georges Declaration on Conservation and Management of Spiny Lobsters (Panulirus argus), 15 May 2015, CRFM	UBA use not specified
Drudi, D. (1998). Fishing for a living is dangerous work. Compensation and Working Conditions, 3-7.	Pre-2000; No specific dive fishery
FAO. (1995). Code of Conduct for Responsible Fisheries. Rome: FAO.	Pre-2000; No specific dive fishery
Pollock, N. W. (2008). Breath-hold diving: performance and safety. Diving and hyperbaric medicine, 38, 79-86.	Breath-hold diving only
Ben-Yami, M. (2000). Risks and dangers in small-scale fisheries: an overview (No. 993427803402676). International Labour Organization.	No specific dive fishery
Béné, C., & Tewfik, A. (2001). Fishing effort allocation and fishermen's decision making process in a multi-species small-scale fishery: Analysis of the conch and lobster fishery in Turks and Caicos Islands. Human Ecology,29(2), 157-186.	Breath-hold diving only
Acott, C. (1994). The Diving Incident Monitoring Study Dive Tables and Dive Computers. *South Pacific Underwater Medicine Society (SPUMS) Journal*, *24*(4), 214–215.	Pre-2000; No specific dive fishery
Acott, C. (1999). A Brief History of Diving and Decompression Illness. South Pacific Underwater Medicine Society, 29(2), 99–109.	Pre-2000
Buzzacott, P. (2006). *Diving injuries amongst Western Australian scuba course graduates*. University of Western Australia.	Recreational diving only
Buzzacott, P. (2012). The Epidemiology of Injury in Diving. In T. Heggie & D. Caine (Eds.), Epidemiology of Injury in Adventure and Extreme Sports (Vol. 58, pp. 57–79). Basel: Karger. https://doi.org/10.1159/000338582	No specific dive fishery
Buzzacott, P., Denoble, P., Dunford, R., & Vann, R. (2009). Dive problems and risk factors for diving morbidity. *Diving and Hyperbaric Medicine*, *39*(4), 205–209.	Recreational diving only

Buzzacott, P., Pikora, T., Heyworth, J., & Rosenberg, M. (2010). Exceeding the limits - Estimated tissue pressures among Western Australian recreational divers. *Diving and Hyperbaric Medicine*, *40*(4), 201–205.	No specific dive fishery
Dovenbarger, J. A., Wachholz, C. J., & Bennett, P. B. (1995). Divers Alert Netwrok (DAN) Accident Data. *SPUMS Journal*, *25*(3), 162–169.	Pre-2000; No specific dive fishery
Ehrhardt, N. (2006). *Integrated study of the spiny lobster fishery in the Atlantic coast of Nicaragua with special emphasis on the issue of diving.* Danish Agency for International Development (DANIDA) Final Report to the Ministry of Development, Industry, and Commerce. Government of Nicaragua. Managua, Nicaragua. 24 May 2006. 113p.	Language barrier
Lemaitre, F., Fahlman, A., Gardette, B., & Kohshi, K. (2009). Decompression sickness in breath-hold divers: A review. *Journal of Sports Sciences*, *27*(14), 1519–1534. https://doi.org/10.1080/02640410903121351	Breath-hold diving only
Levett, D. Z. H., & Millar, I. L. (2008). Bubble trouble: a review of diving physiology and disease. *Postgraduate Medical Journal*, *84*(997), 571–578. https://doi.org/10.1136/pgmj.2008.068320	No specific dive fishery
Naranjo Madrigal, H., & Salas Márquez, S. (2014). Dinámica espacio-temporal del esfuerzo en una pesquería de buceo artesanal multiespecífica y sus efectos en la variabilidad de las capturas: Implicaciones para el manejo sostenible. Spatio-temporal dynamics of fishing effort in a multi-species artisanal diving fishery and its effects on catch variability: insights for sustainable management. *Revista de Biologia Tropical*, *62*(4), 1565–1586. https://doi.org/10.15517/rbt.v62i4.13614	Language barrier
Maillaud, C. (1999). Diving accidents related to sea-cucumber fishing at Nosy Be, Madagascar. *SPC Beche-de-Mer Information Bulletin*, (11), 23–25.	Pre-2000
Naranjo, H., & Salas, S. (2012). Dinámica del Esfuerzo de Una Pesquería Submarina Artesanal. Effort Dynamics of an Artisanal Underwater Fishery. Effort Dynamique de la Pêcherie Traditionnelle Sous - Marine. *Proceedings of the 65th Gulf and Caribbean Fisheries Institute*, 76–83.	Language barrier
Morris, J. A., & Whitfield, P. E. (2009). Biology, ecology, control and management of the invasive Indo-Pacific lionfish: an updated integrated assessment. 2009. NOAA Technical Memorandum NOS NCCOS, 99, 57.	No specific dive fishery
Lenihan, H. S., & Peterson, C. H. (2004). Conserving oyster reef habitat by switching from dredging and tonging to diver-harvesting. Fishery Bulletin, 102(2), 298-305.	No specific dive fishery
Defeo, O., & Castilla, J. C. (1998). Harvesting and economic patterns in the artisanal Octopus mimus (Cephalopoda) fishery in a northern Chile cove.Fisheries Research, 38(2), 121-130.	Pre-2000
Anderson, R. C. (1996, March). The Maldivian tuna livebait fishery–status and trends. In Report and Proceedings of the Maldives/FAO National Workshop on Integrated Reef Resources Management in the Maldives. Malé(pp. 69-92).	Pre-2000
Doolette, D. J., & Craig, D. (1999). Tuna farm diving in South Australia.SPUMS Journal, (29)2, 115-117.	Pre-2000

Lee, H. C., Niu, K. C., Huang, K. L., Tsai, J. D., Shyu, R. K., Shiraki, K., ... & Lin, Y. C. (1994). Diving pattern of fishermen in the Pescadores. Undersea & hyperbaric medicine: journal of the Undersea and Hyperbaric Medical Society, Inc, 21(2), 145-158.	Pre-2000
Sakong, J. (1998). Diving patterns and diving related disease of diving fishermen in Korea. Korean journal of preventive medicine, 31(1), 139-156.	Pre-2000
Olofson, H., & Tiukinhoy, A. (1992). " Plain Soldiers": Muro-Ami Fishing in Cebu. Philippine Studies, 40(1), 35-52.	Pre-2000
Miclat, R. I., Alino, P. M., Aragones, N., Nanola Jr, C., & Aguilar, E. (1991). Pa-Aling: An alternative to muro-ami. Philippine Journal of Fisheries, 1991, 22-48.	Pre-2000
Van Oosterhout, H. (1988). Child labour in the Philippines: The Muro-Ami deep-sea fishing operation. In A. Bequele & J. Boyden (Eds.), Combatting child labour. Geneva: International Labour Office.	Pre-2000
Miller, R. J., & Nolan, S. C. (2008). Management methods for a sea urchin dive fishery with individual fishing zones. Journal of Shellfish Research, 27(4), 929-938.	UBA use not specified
Bradbury, A. (1994). Sea cucumber fishery in Washington State. SPC Beche-de-mer Information Bulletin, 6, 15-16.	Pre-2000
Harbo, R., & Convey, L. (1997). Abalone dive fishery (closed). Can. MS. Rep. Fish. Aquat. Sci, 2369, 86-92.	Pre-2000
Conand, C., & Bryne, M. (1993). A review of recent developments in the world sea cucumber fisheries. Marine fisheries review, 55(4), 1-13.	Pre-2000
Nayar, R. (2009). The sea urchin fishery in Grenada: A case study of social-Ecological Networks. *MS Thesis, University of Manitoba*, 126.	Breath-hold diving only
Neuman, T. S. (2002). Arterial gas embolism and decompression sickness. *News in Physiological Sciences : An International Journal of Physiology Produced Jointly by the International Union of Physiological Sciences and the American Physiological Society*, *17*(4), 77–81.	No specific dive fishery
NOAA. (1997). Diving physiology. *NOAA Diving Manual Diving for Science and Technology, 4th Edition*, 0–37.	Pre-2000; No specific dive fishery
Organización Panamericana de la Salud. (2004). *Derechos Humanos y Discapacidad entre los Pueblos Indígenas*. Puerto Lempira, Gracias a Dios, Honduras.	Language barrier
Schagatay, E. (2014). Human breath-hold diving ability and the underlying physiology. *Human Evolution*, *29*(1–3), 125–140.	No specific dive fishery; Breath-hold diving only
Schipke, J. D., Gams, E., & Kallweit, O. (2006). Decompression sickness following breath-hold diving. *Research in Sports Medicine*, *14*(3), 163–178. https://doi.org/10.1080/15438620600854710	Breath-hold diving only
Tetzlaff, K., & Thorsen, E. (2005). Breathing at depth: Physiologic and clinical aspects of diving while breathing compressed gas. *Clinics in Chest Medicine*, *26*(3), 355–380. https://doi.org/10.1016/j.ccm.2005.05.001	No specific dive fishery
Wade, C., & Hayashi, E. (1978). Incidence of dysbaric osteonecrosis in Hawaii's diving fishermen. *Undersea Biomedical Research*, *5*(2), 137–147. Retrieved from http://archive.rubicon-foundation.org/xmlui/handle/123456789/2705	Pre-2000

Lepawsky, M., & Harbo, R. M. (1999). The incidence of decompression illness amongst commercial geoduck divers in British Columbia - a twenty-two year study.	Pre-2000
Kawashima, M., Tamura, H., Takao, K., & Nagayoshi, I. (1991). Dysbaric osteonecrosis and diving profile. In *Undersea and Hyperbaric Medical Society Annual Scientific Meeting*. San Diego, CA: UHMS Inc. Retrieved from http://archive.rubicon-foundation.org/xmlui/handle/123456789/6403	Pre-2000
Castilla, J. C., Manriquez, P., Alvarado, J., Rosson, A., Pino, C., Espoz, C., ... & Defeo, O. (1998). Artisanal" caletas" as units of production and co-managers of benthic invertebrates in Chile. Canadian Special Publication of Fisheries and Aquatic Sciences, 407-413.	Pre-2000
Conand, C. (2001). Overview of sea cucumber fisheries over the last decade—what possibilities for a durable management. In Echinoderms 2000. Proceedings of the Tenth International Conference, Dunedin. Lisse: Swets & Zeitlinger (pp. 339-344).	Unable to access
Doherty, R. J. (1990). Canada's dive fishery comes of age. Pacific fishing, 12, 116-122.	Pre-2000
Babcock, E. A., Pikitch, E. K., McAllister, M. K., Apostolaki, P., & Santora, C. (2005). A perspective on the use of spatialized indicators for ecosystem-based fishery management through spatial zoning. ICES Journal of Marine Science: Journal du Conseil, 62(3), 469-476.	No specific dive fishery
Prince, J., Walters, C., Ruiz-Avila, R., & Sluczanowski, P. (1998). Territorial user's rights and the Australian abalone (Haliotis sp.) fishery. Canadian Special Publication of Fisheries and Aquatic Sciences, 367-376.	Pre-2000
Smith, M. D., & Wilen, J. E. (2005). Heterogeneous and correlated risk preferences in commercial fishermen: The perfect storm dilemma. Journal of Risk and Uncertainty, 31(1), 53-71.	Breath-hold diving only
Kronen, M., & Vunisea, A. (2007). Women never hunt–but fish: highlighting equality for women in policy formulation and strategic planning in the coastal fisheries sector in Pacific Island countries. SPC Women in Fisheries Information Bulletin, 17, 3-15.	Breath-hold diving only
SASAKI, A., OHTSUKA, R., & SUZUKI, T. (1983). Work styles of Okinawan diving-fishers in relation to decompression sickness and physical complaints.Journal of human ergology, 12(2), 219-222.	Pre-2000
Rafael, P. R., Rene, L. V., Rosalía, Á. C. C., & Elba, M. V. N. (2015). Salud ocupacional en buceo con hooka de una cooperativa pesquera del noroeste de México.	Language barrier
Winterbottom, M., Haughton, M., Mutrie, E., & Grieve, K. (2012). Management of the spiny lobster fishery in CARICOM countries: status and recommendations for conservation. In Proceedings of the Gulf and Caribbean Fisheries Institute (Vol. 64, pp. 456-462).	No specific dive fishery
Gallardo Fernández, G. L., Stotz, W., Aburto, J., Mondaca, C., & Vera, K. (2011). Emerging commons within artisanal fisheries. The Chilean territorial use rights in fisheries (TURFs) within a broader coastal landscape. International Journal of the Commons, 5(2), 459-484.	UBA use not specified

Dawson, R., Bourke, A., & Cross, M. (1998). A survey to quantify the prevalence of aseptic bone necrosis in two populations of diving fishermen in the Philippines. In *Undersea & Hyperbaric Medical Society, Annual Meeting*. UHMS Inc. Retrieved from http://archive.rubicon-foundation.org/681	Pre-2000
Verwork, C., Bourke, A., Dawson, R., & Cross, M. (1998). A study of the diving practices and the indicence of decompression sickness in a population of indigenous hookah diving fishermen in the Philippines. (i: Madridejos). In *Undersea and Hyperbaric Medical Society Annual Scientific Meeting*. UHMS Inc. Retrieved from http://archive.rubicon-foundation.org/666	Pre-2000
Bourke, A., Verwork, C., Dawson, R., & Cross, M. (1998). A study of the diving practices and the incidence of decompression sickness in a population of indigenous diving fishermen in the Philippines (Noc Nocan). In *Undersea and Hyperbaric Medical Society Annual Scientific Meeting*. UHMS Inc. Retrieved from http://archive.rubicon-foundation.org/667%0D%0D%0A	Pre-2000
Taya, Y., Lehner, C., Lin, T., Mano, Y., Kawashima, M., Shidara, F., … Wilson, M. (1994). Decompression sickness and dysbaric osteonecrosis risk in Japanese dive profiles: a sheep model. In *Undersea and Hyperbaric Medical Society, Inc. Annual Scientific Meeting*. Denver, CO: UHMS Inc. Retrieved from http://archive.rubicon-foundation.org/5633	Pre-2000
Lam, T. H., Yau, K. P., & O'kelly, F. J. (1985). Dysbaric hazard of a new fishing method in Hong Kong: Case report. *British Journal of Industrial Medicine*, *42*(3), 209. Retrieved from http	Pre-2000
Tanaka, Y., Ohtsuka, R., & Tsuguyoshi, S. (1981). Implication of modern technology to geographical distribution ofJapanese diving-fishing. *J. Human Ergol.*, *10*, 3–12.	Pre-2000
Béné, C., Devereux, S., & Roelen, K. (2015). Social Protection and Sustainable Natural Resource Management: Initial Findings and Good Practices from Small-Scale Fisheries. Rome: Food and Agriculture Organization of the United Nations.	No specific dive fishery
Aswani, S., & Hamilton, R. J. (2004). Integrating indigenous ecological knowledge and customary sea tenure with marine and social science for conservation of bumphead parrotfish (Bolbometopon muricatum) in the Roviana Lagoon, Solomon Islands. Environmental Conservation, 31(01), 69-83.	No specific dive fishery
Tsujimura, T. N., Alonso Población, E., Amaral, L. D. R., & Rodrigues, P. (2012). Safety at sea assessment in the Timor-Leste small-scale fisheries sector. Technical report.	No specific dive fishery
Kawashima, M., Tamura, H., Noro, Y., Takao, K., Yoshida, K., Kitano, M., & Maho, Y. (1996). Studies of decompression sickness in Japanese divers. In *Undersea and Hyperbaric Medical Society Annual Scientific Meeting*. UHMS Inc. Retrieved from http://archive.rubicon-foundation.org/xmlui/handle/123456789/539	Pre-2000
Fields, L. L. (2001). Out on the Deep Blue: Women, Men, and the Oceans They Fish. Macmillan.	No specific dive fishery
Martinez, D. P. (2004). Identity and ritual in a Japanese diving village: The making and becoming of person and place. University of Hawaii Press.	UBA use not specified

Martins, V. S., Schiavetti, A., & Souto, F. J. (2011). Ethnoecological knowledge of the artisan fishermen of octopi (Octopus spp.) in the community of Coroa Vermelha (Santa Cruz Cabrália, Bahia). Anais da Academia Brasileira de Ciências, 83(2), 513-522.	UBA use not specified
Figueroa, J., & Mero, D. (2013). Length of capture and reproduction of green spiny lobster Panulirus gracilis (Decapoda: Palinuridae) from the coast of Manabí, Ecuador. Revista de Biología Tropical, 61(3), 1189-1199.	Language barrier
Khoufi, W., & Bakhrouf, A. (2012). Stock assessment of the Common Octopus (Octopus vulgaris) in Monastir; the Mid-eastern Coast of Tunisia. International Journal of Marine Science, 2(1).	Breath-hold diving only
Campbell, A. (2000). Review of northern abalone, *Haliotis kamtschatkana*, stock status in British Columbia. Canadian Special Publication of Fisheries and Aquatic Sciences, 41-50.	Unable to access
Campbell, A., Harbo, R. M., & Hand, C. M. (1998). Harvesting and distribution of Pacific geoduck clams, Panopea abrupta, in British Columbia. Canadian Special Publication of Fisheries and Aquatic Sciences, 349-358.	Pre-2000
Prince, J. D., Peeters, H., Gorfine, H., & Day, R. W. (2008). The novel use of harvest policies and rapid visual assessment to manage spatially complex abalone resources (Genus Haliotis). Fisheries Research, 94(3), 330-338.	UBA use not specified
Giraspy, D. A. B., & Ivy, G. (2005). Australia's first commercial sea cucumber culture and sea ranching project in Hervey Bay, Queensland, Australia. SPC Beche-de-mer Information Bulletin, 21, 29-31.	Breath-hold diving only
Rothaus, D. P., Vadopalas, B., & Friedman, C. S. (2008). Precipitous declines in pinto abalone (Haliotis kamtschatkana kamtschatkana) abundance in the San Juan Archipelago, Washington, USA, despite statewide fishery closure. Canadian Journal of Fisheries and Aquatic Sciences, 65(12), 2703-2711.	UBA use not specified
Heizer, S., Thomas, G., & Hobbs, K. (1997). Red sea urchin dive fishery update. Can. MS. Rep. Fish. Aquat. Sci, 2369, 93-102.	Pre-2000
Goodwin, C. L. (1990). Commercial geoduck dive fishery. In J. W. Armstrong, & A. E. Copping (Eds.), Status and management of Puget Sound's biological resources. Edited by JW Armstrong and AE Copping. Proceedings of a Forum on Puget Sound's Biological Resources—Status and Management, Seattle, Wash (pp. 24-31).	Pre-2000
Woodby, D., Larson, R., & Rumble, J. (2000). Decline of the Alaska abalone (*Haliotis* spp.) fishery and prospects for rebuilding the stock. Canadian Special Publication of Fisheries and Aquatic Sciences, 25-31.	UBA use not specified
Conand, C., Jerome, A., Dijoux, N., & Garryer, J. (1992). Economic reasons, ecological actions and social consequences in the Mexican sea cucumber fishery. Beche-de-mer Information Bulletin, 15, 4-12.	Pre-2000
Phillips, B. F., Chubb, C. F., & Melville-Smith, R. (2000). The status of Australia's rock lobster fisheries. Spiny Lobster Fisheries and Culture, 45-77.	Unable to access
Tracey, S. R., & Lyle, J. M. (2011). Linking scallop distribution and abundance with fisher behaviour: implication for management to avoid repeated stock collapse in a recreational fishery. Fisheries Management and Ecology, 18(3), 221-232.	UBA use not specified

Smith, M. D. (2002). Two econometric approaches for predicting the spatial behavior of renewable resource harvesters. Land Economics, 78(4), 522-538.	Breath-hold diving only
Therkildsen, N. O., & Petersen, C. W. (2006). A review of the emerging fishery for the sea cucumber Cucumaria frondosa: Biology, policy, and future prospects. BECHE-DE-MER, 200616.	UBA use not specified
Grobler, C. A. F., & Noli-Peard, K. R. (1997). Jasus lalandii fishery in post-independence Namibia: monitoring population trends and stock recovery in relation to a variable environment. Marine and Freshwater Research, 48(8), 1015-1022.	Pre-2000
Castro, L. R. S. (1995). Management options of the commercial dive fisheries for sea cucumbers in Baja California, Mexico. SPC Beche-de-Mer Information Bulletin, 7, 20.	Pre-2000
Lokani, P., Polon, P., Lari, R., Dalzell, P., & Adams, T. J. H. (1995). Fisheries and management of beche-de-mer fisheries in Western Province of Papua New Guinea. SPC Integrated Coastal Fisheries Management Project Technical Document, (11), 267-275.	Pre-2000
Okey, T. A., Banks, S., Born, A. F., Bustamante, R. H., Calvopiña, M., Edgar, G. J., ... & Salazar, S. (2004). A trophic model of a Galápagos subtidal rocky reef for evaluating fisheries and conservation strategies. Ecological Modelling, 172(2), 383-401.	No specific dive fishery
Lokani, P. (1996). Illegal fishing for sea-cucumber (beche-de-mer) by Papua New Guinea artisanal fishermen in the Torres Strait protected zone. SPC Beche-de-mer Infor. Bull., 8.	Pre-2000
Morgan, A., & Archer, J. (1999). Overview: aspects of sea cucumber industry research and development in the South Pacific. SPC Beche-de-mer Inf. Bull, 1, 15-17.	Pre-2000
James, M. (2008). Co-operative management of the geoduck and horse-clam fishery in British Columbia. FAO FISHERIES TECHNICAL PAPER, 504, 397.	Unable to access
Fulton, E. A., & Smith, A. D. M. (2004). Lessons learnt from a comparison of three ecosystem models for Port Phillip Bay, Australia. African Journal of Marine Science, 26(1), 219-243.	UBA use not specified
Addis, P., Secci, M., Manunza, A., Corrias, S., Niffoi, A., & Cau, A. (2009). A geostatistical approach for the stock assessment of the edible sea urchin, Paracentrotus lividus, in four coastal zones of Southern and West Sardinia (SW Italy, Mediterranean Sea). Fisheries Research, 100(3), 215-221.	UBA use not specified
Wilson, D. C. (1999). Fisheries science collaborations: the critical role of the community. (Research Publication No. 45). Hertshals, Denmark: Institute for Fisheries Management and Coastal Community Development, 24 p.	Pre-2000
Mayfield, S., McGarvey, R., Carlson, I. J., & Dixon, C. (2008). Integrating commercial and research surveys to estimate the harvestable biomass, and establish a quota, for an “unexploited” abalone population. ICES Journal of Marine Science: Journal du Conseil, 65(7), 1122-1130.	UBA use not specified
Addis, P., Secci, M., Angioni, A., & Cau, A. (2012). Spatial distribution patterns and population structure of the sea urchin Paracentrotus lividus (Echinodermata: Echinoidea), in the coastal fishery of western Sardinia: a geostatistical analysis. Scientia Marina, 76(4), 733-740.	UBA use not specified

Narvarte, M., González, R., Medina, A., Avaca, M. S., Ginsberg, S., & Aliotta, S. (2012). Short term impact of artisanal dredges in a Patagonian mussel fishery: Comparisons with commercial diving and control sites. *Marine Environmental Research*, *73*, 53–61. https://doi.org/10.1016/j.marenvres.2011.10.010	Unable to access
Olofson, H., Canizares, B., & de Jose, F. (2000b). A People in Travail II: 'Livelihood projects,' slapstick 'development,' and development irony among veteran muro-ami fisherfolk of southern Cebu. Philippine Quarterly of Culture and Society, 28(3), 317-354.	Breath-hold diving only
Olofson, H., de Jose, F., and Cañizares, B. (2000c). A People in Travail III: Veteran muro-ami families in cooperatives. Philippine Quarterly of Culture and Society 28(4): 498-511.	Breath-hold diving only
Olofson, H., Canizares, B., & de Jose, F. (2000a). A People in Travail I: Labor relations history of veteran muro-ami fisherfolk in the Central Philippines. Philippine Quarterly of Culture and Society, 28(2), 224-262.	Breath-hold diving only

APPENDIX D. INVENTORY OF DIVE FISHERIES

All dive fisheries identified in the reviewed literature are listed here. Fishery codes are non-contiguous in some cases because fisheries originally identified and given a code were later removed. This was due to merging with other identified fisheries that were originally thought to be separate, but were found to be in reference to the same fishery. Sources that reference each fishery are identified by source codes which correspond to documents listed in Appendix B. The process for determining characteristics such as number of divers, average dive depth, maximum dive depth, and fishery status is described in Section 2. Target species codes are listed in Appendix E. When no information was available for a characteristic, it was noted as 'no information' (NI).

Fishery ID	Fishery	Target species group	Target species	Scale	Sector(s)	Region	Country or Territory	Sources	Number of divers	Dive method employed	Avg. dive depth (ft)	Max. dive depth (ft)	Fishery status
F002	Seri Callo de Hacha ('Scallop')	MOLLU	biv005, biv006	small-scale	commercial	North America	Mexico	SS0027, SS0155	75	hookah	18.04	NI	open
F003	Grenada lobster and conch	CRUST, MOLLU	mal000, gas001	small-scale	commercial	Caribbean	Grenada	SS0040, SS0049, SS0051, SS0009	NI	SCUBA, free-dive	NI	NI	open
F004	Tanzania sea cucumber	ECHIN	hol000	small-scale	commercial	Africa	Tanzania	SS0057, SS0058, SS0142, SS0057	400	SCUBA	NI	NI	open
F005	Victoria abalone	MOLLU	gas008	small-scale	commercial	Aus/NZ	Australia	SS0149, S0152, SS0133	71	hookah	NI	NI	open
F007	Chagos illegal sea cucumber	ECHIN	hol000	small-scale	commercial	South Asia	Chagos Islands	SS0134	NI	Unspecified UBA	NI	NI	closed

F008	Oman sea cucumber (closed)	ECHIN	hol007	small-scale	commercial	Middle East	Oman	SS0134	NI	SCUBA, free-dive	NI	NI	closed
F009	Maldives sea cucumber (UBA banned)	ECHIN	hol000	small-scale	commercial	South Asia	Maldives	SS0134	NI	Unspecified UBA	NI	NI	closed
F011	Costa Rica dive fishery	NI	NI	NI	NI	Central America	Costa Rica	SS0064	NI	hookah	NI	NI	open
F012	Ecuador dive fishery	NI	NI	NI	NI	South America	Ecuador	SS0064	NI	hookah	NI	NI	open
F013	Brazil dive fishery	NI	NI	NI	NI	South America	Brazil	SS0064, SS0216	NI	hookah	NI	NI	open
F014	San Felipe multi-species	CRUST, MOLLU, FISH	mal001, cep003, act007	small-scale	commercial	North America	Mexico	SS0064, SS0097, SS0177	125	hookah	NI	NI	open
F015	Rio Lagartos multi-species	CRUST, MOLLU, FISH	mal001, cep003, act007	small-scale	commercial	North America	Mexico	SS0064, SS0208, SS0097, SS0177	400	hookah	NI	NI	open
F016	British Columbia red sea urchin	ECHIN	ech005	small-scale	commercial	North America	Canada	SS0214, SS0114, SS207	NI	SCUBA	NI	NI	open
F017	British Columbia giant red sea cucumber	ECHIN	hol004	small-scale	commercial	North America	Canada	SS0214, SS0197	85	Unspecified UBA	NI	NI	open
F018	British Columbia sea cucumbers (non-Giant red sea cucumber)	ECHIN	hol000	NI	NI	North America	Canada	SS0214	NI	Unspecified UBA	NI	NI	open
F019	British Columbia commercial geoduck	MOLLU	biv010, biv004	small-scale	commercial	North America	Canada	SS0214, SS0215, SS0093, SS0186	86	hookah	40	40	open

F020	Madagascar Antsiranana Bay sea cucumber	ECHIN	hol	NI	NI	Africa	Madagascar	SS0020	NI	SCUBA	NI	NI	open
F021	Papua New Guinea sea cucumber (closed)	ECHIN	hol	small-scale	None - fishery closed	Oceania	Papua New Guinea	SS0222, SS0005, SS0047	NI	hookah, free-dive	NI	NI	closed
F022	Vanuatu sea cucumber	ECHIN	hol	small-scale	commercial, subsistence	Oceania	Vanuatu	SS0222, SS0047	NI	Unspecified UBA	NI	NI	open
F023	Solomon Islands sea cucumber (closed)	ECHIN	hol	small-scale, industrial	None - fishery closed	Oceania	Solomon Islands	SS0222, SS0047	NI	Unspecified UBA	NI	NI	closed
F024	Scotland king scallop	MOLLU	biv008	small-scale	commercial	Europe	Scotland	SS0182	22	Unspecified UBA	182	282	open
F025	Samoa sea cucumber	ECHIN	hol	small-scale	subsistence	Oceania	Samoa	SS0222, SS0047	NI	Unspecified UBA	NI	NI	open
F026	Tuvalu multi-species (closed)	ECHIN	hol002, hol006	small-scale, industrial	None - fishery closed	Oceania	Tuvalu	SS0222, SS0047	NI	Unspecified UBA	NI	NI	closed
F027	Marshall Islands sea cucumber (closed)	ECHIN	hol	small-scale	None - fishery closed	Oceania	Marshall Islands	SS0222, SS0047	NI	Unspecified UBA	NI	NI	closed
F028	Tonga sea cucumber (closed)	ECHIN	hol	small-scale	commercial, subsistence	Oceania	Tonga	SS0222, SS0047	NI	SCUBA	NI	NI	closed
F029	New Caledonia sea cucumber	ECHIN	hol	small-scale	commercial, subsistence	Oceania	New Caledonia	SS0222	NI	Unspecified UBA	NI	NI	open
F030	Palau sea cucumber (closed)	ECHIN	hol006, hol007, hol008, hol009, hol010, hol011	small-scale	None - fishery closed	Oceania	Palau	SS0222, SS0047	NI	Unspecified UBA	NI	NI	closed

F031	Kiritbati sea cucumber	ECHIN	hol	small-scale	commercial, subsistence	Oceania	Kiribati	SS0222	NI	Unspecified UBA	NI	NI	open
F032	Cook Islands sea cucumber	ECHIN	hol	small-scale	subsistence	Oceania	Cook Islands	SS0222, SS0047	NI	Unspecified UBA	NI	NI	open
F033	French Polynesia sea cucumber (closed)	ECHIN	hol	small-scale	None - fishery closed	Oceania	French Polynesia	SS0222, SS0047	NI	Unspecified UBA	NI	NI	closed
F034	American Samoa reef fish	FISH	fsh	small-scale	commercial, subsistence	Oceania	American Samoa	SS0224	NI	SCUBA	NI	NI	closed
F035	New Zealand geoduck	MOLLU	biv	NI	commercial	Aus/NZ	New Zealand	SS0003	NI	Unspecified UBA	NI	NI	open
F036	Seychelles sea cucumber	ECHIN	hol000	large-scale	commercial	Africa	Seychelles	SS0134	100	SCUBA	NI	NI	open
F037	Sri Lankan sea cucumber	ECHIN	hol000	industrial, small-scale	commercial	South Asia	Sri Lanka	SS0134	280	SCUBA	NI	NI	open
F038	Eritrea sea cucumber	ECHIN	hol000	small-scale	commercial	Africa	Eritrea	SS0134	1007	hookah, SCUBA	NI	NI	open
F039	Kenyan sea cucumber	ECHIN	hol000	small-scale	commercial, subsistence	Africa	Kenya	SS0134	NI	SCUBA, free-dive	NI	NI	open
F040	Madagascar illegal sea cucumber	ECHIN	hol000	NI	commercial	Africa	Madagascar	SS0134	NI	SCUBA	NI	NI	open
F041	Chilean abalone (loco)	MOLLU	gas002	small-scale	commercial	South America	Chile	SS0054, SS0132, SS0204, SS0171	NI	hookah	NI	NI	open
F042	Colombia lobster and conch	CRUST, MOLLU	mal000, gas001	small-scale	commercial	Central America	Colombia	SS0028	750	hookah, SCUBA	NI	NI	open
F043	Xingu River ornamental fish	FISH	fsh003	small-scale	commercial	South America	Brazil	SS0160	NI	SCUBA, free-dive	NI	NI	open

F044	Antigua and Barbuda conch	MOLLU	gas	small-scale	commercial	Caribbean	Antigua and Barbuda	SS0052	40	SCUBA	NI	NI	open
F045	British Columbia octopus	MOLLU	cep	NI	commercial	North America	Canada	SS0013	NI	SCUBA	NI	NI	open
F046	Nunavut clam	MOLLU	biv	small-scale	commercial	North America	Canada	SS0225	10	SCUBA	NI	NI	open
F049	Vietnam sea cucumber (Ninh Van and Ly Son Island)	ECHIN	hol	small-scale	commercial, subsistence	Southeast Asia	Vietnam	SS0032, SS0019	1250	hookah	147.6	196.8	open
F050	Tasmania salmon farms	FISH	fsh	NI	commercial	Aus/NZ	Australia	SS0088, SS0023	100	hookah	NI	NI	open
F051	Chinese dive fishery	NI	NI	NI	NI	East Asia	China	SS0092	NI	hookah, SCUBA	NI	NI	open
F052	Grenada sea egg	ECHIN	ech	NI	NI	Caribbean	Grenada	SS0046	110	SCUBA, free-dive	NI	NI	open
F053	Miskito Keys Caribbean spiny lobster	CRUST	mal001	small-scale	commercial	Central America	Nicaragua, Honduras	SS0031, SS0176, SS0188, SS0099, SS0015	700	SCUBA	NI	NI	open
F054	Metlakatla	NI	NI	NI	NI	North America	United States	SS0094	71	hookah, SCUBA	NI	NI	open
F056	Isla Mujeres lobster	CRUST	mal	NI	NI	North America	Mexico	SS0103	NI	hookah, SCUBA	NI	NI	open
F057	Thai Urak Lawoi multispecies	FISH, CRUST, ECHIN, MOLLU, SHELL	crb000, hol000, mal000, biv009, fsh000, she000, mar000	small-scale, indigenous	commercial, subsistence (indigenous)	Southeast Asia	Thailand	SS0178, SS0062, SS0063, SS0064, SS0233	400	hookah	NI	NI	open

F058	Australia tuna	FISH	fsh	NI	commercial	Aus/NZ	Australia	SS0179	NI	Unspecified UBA	NI	NI	open
F059	New Zealand salmon	FISH	fsh	NI	NI	Aus/NZ	New Zealand	SS0180	NI	SCUBA	NI	NI	open
F060	Hawaiian dive fishery	CORAL, FISH	ant000, fsh000	small-scale	commercial	North America	United States	SS0183, SS0091	NI	SCUBA	205	350	open
F061	California abalone (closed)	MOLLU	gas008	small-scale	commercial	North America	United States	SS00184	NI	hookah	NI	NI	open
F062	California red sea urchin	ECHIN	ech005	small-scale	commercial	North America	United States	SS0185, SS0207	385.5	hookah	NI	NI	open
F063	Turkey sponge and shellfish	SPONG, SHELL	she000, spo000	NI	NI	Southeast Europe	Turkey	SS0187	NI	hookah, SCUBA	NI	NI	open
F064	Maine scallop	MOLLU	biv017	NI	NI	North America	United States	SS0190, SS0192	334.5	SCUBA	95	130	open
F065	Western Australia wild pearl oyster drift fishery	MOLLU	biv009	small-scale	commercial	Aus/NZ	Australia	SS0191, SS0023	NI	hookah	103.32	147.6	open
F067	Barbados spiny spotted lobster	CRUST	mal002	small-scale	NI	Caribbean	Barbados	SS0009	NI	SCUBA, free-dive	NI	NI	open
F073	Galicia sea urchin	ECHIN	ech	small-scale	NI	Western Europe	Spain	SS0108	255	hookah, free-dive	NI	NI	open
F074	St.Croix multispecies	CRUST, MOLLU, FISH	mal000, gas001, fsh000	small-scale	commercial	Caribbean	United States	SS0123	130	SCUBA	NI	NI	open
F075	Indonesia ornamental fish	FISH	fsh	small-scale	commercial	Southeast Asia	Indonesia	SS0056	NI	hookah	NI	NI	open
F076	Hawaii ornamental fish	FISH	fsh003	small-scale	commercial	Oceania	United States	SS0025	37	SCUBA	NI	NI	open

F077	Nova Scotia sea urchin	ECHIN	ech002	small-scale	commercial	North America	Canada	SS0050, SS0207	NI	SCUBA	26.24	49.2	open
F079	Mexico black murex	MOLLU	gas	small-scale	commercial	North America	Mexico	SS0145	NI	hookah	NI	NI	open
F080	Marinduque, Philippines dive fishery	NI	NI	NI	NI	Southeast Asia	Philippines	SS0056	200	hookah	NI	NI	open
F081	Japan multispecies	MOLLU, ECHIN, SHELL	gas008, ech000, she000	NI	NI	East Asia	Japan	SS0189	NI	hookah, SCUBA	NI	NI	open
F082	Fiji sea cucumber	ECHIN	hol000	industrial, small-scale	commercial, subsistence	Oceania	Fiji	SS0014, SS0222, SS0024, SS0047	67.5	SCUBA, free-dive	NI	NI	open
F083	Taiwan dive fishery	NI	NI	NI	NI	East Asia	Taiwan	SS0096	NI	NI	70.5 ± 33.5 ft	164	open
F084	Huentelauquén, Chile kelp, loco, and keyhole limpets	ALGAE, MOLLU	pha000, gas002, gas010	small-scale	commercial	South America	Chile	SS0173	NI	hookah	NI	NI	open
F085	Tasmania abalone	MOLLU	gas004	NI	NI	Aus/NZ	Australia	SS0212, SS0022, SS0023, SS0152, SS0133	125	Unspecified UBA	NI	NI	open
F086	South Australia greenlip and blacklip abalone	MOLLU	gas003, gas004	NI	commercial	Aus/NZ	Australia	SS0113, SS0079, SS0023, SS0133	81	hookah	NI	NI	open
F087	British Columbia abalone	MOLLU	gas008, gas007	industrial	commercial	North America	Canada	SS0199, SS0161, SS0240, SS0166	NI	SCUBA	NI	NI	closed
F088	Papua New Guinea rock lobster	CRUST	mal004	NI	commercial, traditional	Oceania	Papua New Guinea	SS0119	NI	hookah, free-dive	NI	NI	open

F089	Torres Strait rock lobster	CRUST	mal004	NI	commercial, traditional	Aus/NZ	Australia	SS0119	NI	hookah, free-dive	NI	NI	open
F090	Alaska sea cucumber	ECHIN	hal004	small-scale	commercial	North America	United States	SS0197	174	SCUBA	NI	NI	open
F091	Washington sea cucumber	ECHIN	hal004	small-scale	commercial	North America	United States	SS0197	NI	hookah, SCUBA	NI	NI	open
F092	Oregon sea cucumber	ECHIN	hal004	small-scale	commercial	North America	United States	SS0197	2	SCUBA	NI	NI	open
F093	California sea cucumber	ECHIN	hal004, hal001	small-scale	commercial	North America	United States	SS0197	95	Unspecified UBA	NI	NI	open
F094	Corn Islands Caribbean spiny lobster	CRUST	mal001	small-scale	commercial	Central America	Nicaragua	SS0111, SS0015	115	SCUBA	NI	NI	open
F095	Chilean multi-species	MOLLU, ECHIN, CRUST, ALGAE	gas000, ech005, gas010, ech000, crs000, pha000, tun000	small-scale	commercial	South America	Chile	SS0204, SS054, SS0207	13,199	hookah, free-dive	NI	98.4	open
F096	Norway fish farms	FISH	act005	small-scale	commercial	Europe	Norway	SS0181	NI	Unspecified UBA	NI	131.2	open
F097	South Australia tuna farms	FISH	fsh	NI	NI	Aus/NZ	Australia	SS0023	NI	Unspecified UBA	NI	NI	open
F098	Australia multispecies reef fishery	FISH, MOLLU, SHELL	fsh001, gas000, she000	NI	NI	Aus/NZ	Australia	SS0023	NI	Unspecified UBA	NI	NI	open
F099	New South Wales abalone	MOLLU	gas004	NI	NI	Aus/NZ	Australia	SS0023	35	Unspecified UBA	NI	NI	open
F100	Victoria abalone	MOLLU	gas003, gas004	NI	NI	Aus/NZ	Australia	SS0023	71	Unspecified UBA	NI	NI	open

F101	Western Australia abalone	MOLLU	gas003, gas004, gas011	small-scale	commercial	Aus/NZ	Australia	SS0023	105	hookah, SCUBA	65.6	98.4	open
F102	Fiji reef fish	FISH	fsh001	NI	NI	Oceania	Fiji	SS0005	NI	SCUBA	NI	NI	closed
F103	Papua New Guinea reef fish	FISH	fsh001	small-scale	NI	Oceania	Papua New Guinea	SS0005	NI	hookah	NI	NI	closed
F104	Jamaica multi-species	CRUST, MOLLU, FISH	mal001, gas001, fsh000	small-scale	commercial	Caribbean	Jamaica	SS0016, SS0015, SS0060, SS0007	NI	hookah, SCUBA, free-dive	NI	NI	open
F105	Puerto Cabezas Caribbean spiny lobster	CRUST	mal001	industrial	commercial	Caribbean	Nicaragua	SS0015	1496	SCUBA	NI	NI	open
F107	Northern Territories pearl oyster	MOLLU	biv009	NI	NI	Aus/NZ	Australia	SS0023	NI	Unspecified UBA	NI	NI	open
F108	St. Kitts and Nevis Caribbean spiny lobster	CRUST	mal001	small-scale	NI	Caribbean	St. Kitts and Nevis	SS0009	NI	SCUBA	NI	NI	closed
F109	St. Vincent and Grenadines Caribbean spiny lobster	CRUST	mal001	NI	commercial	Caribbean	St. Vincent and Grenadines	SS0009	NI	SCUBA	NI	NI	open
F110	Belize Caribbean spiny lobster	CRUST	mal001	NI	NI	Caribbean	Belize	SS0009	NI	Unspecified UBA	NI	NI	closed
F111	Dominica Caribbean spiny lobster	CRUST	mal001	NI	NI	Caribbean	Dominica	SS0009	NI	Unspecified UBA	NI	NI	closed
F112	St. Lucia Caribbean spiny lobster	CRUST	mal001	NI	NI	Caribbean	St. Lucia	SS0009	NI	Unspecified UBA	NI	NI	closed
F113	Turks and Caicos	CRUST, MOLLU	mal001, gas001	small-scale	NI	Caribbean	Turks and Caicos	SS0009, SS0064	NI	hookah	NI	NI	closed

	lobster and conch												
F114	Haiti Caribbean spiny lobster	CRUST	mal001	NI	NI	Caribbean	Haiti	SS0009	NI	hookah	NI	NI	open
F115	Peru scallop	MOLLU	biv002	NI	NI	South America	Peru	SS0146	NI	hookah	NI	NI	open
F116	Punta Allen, Quintana Roo Caribbean spiny lobster	CRUST	mal001	small-scale	commercial	North America	Mexico	SS0114	NI	Unspecified UBA	NI	NI	open
F117	New Zealand rock lobster	CRUST	mal005, mal006	NI	NI	Aus/NZ	New Zealand	SS0114	NI	Unspecified UBA	NI	NI	closed
F118	Maine green sea urchin	ECHIN	ech002	small-scale	commercial	North America	United States	SS0185, SS0192, SS0207	904	SCUBA	70	70	open
F119	Western Australia pearl aquaculture	MOLLU	biv009	NI	NI	Aus/NZ	Australia	SS0191	NI	hookah	NI	NI	open
F120	Queensland pearl oyster	MOLLU	biv009	NI	NI	Aus/NZ	Australia	SS0023	NI	Unspecified UBA	NI	NI	open
F121	British Columbia recreational geoduck	MOLLU	biv010	small-scale	recreational	North America	Canada	SS0215	NI	Unspecified UBA	NI	NI	open
F122	British Columbia First Nations geoduck	MOLLU	biv010	NI	NI	North America	Canada	SS0215	NI	Unspecified UBA	NI	NI	open
F124	Baja California sea urchin	ECHIN	ech005, ech007	small-scale	commercial	North America	Mexico	SS0207	291	hookah	NI	98.4	open
F125	New Brunswick, Canada urchin	ECHIN	ech002	small-scale	commercial	North America	Canada	SS0207	NI	Unspecified UBA	NI	NI	open

F127	Alaska urchin	ECHIN	ech002, ech005	small-scale	commercial	North America	United States	SS0207	95	Unspecified UBA	NI	NI	open
F128	South Korea multispecies	MOLLU, ECHIN	biv018, biv019, biv020, biv021, ech008, ech009, ech010, ech011	small-scale	commercial	East Asia	South Korea	SS0207	NI	hookah	NI	NI	open
F130	Balaeric Islands sea urchin	ECHIN	ech000	NI	NI	Europe	Spain	SS0207	NI	SCUBA	NI	NI	open
F131	Washington sea urchin	ECHIN	ech002, ech005	small-scale	commercial	North America	United States	SS0207	NI	Unspecified UBA	NI	NI	open
F132	Oregon sea urchin	ECHIN	ech005, ech007	small-scale	commercial	North America	United States	SS0207	NI	hookah	NI	NI	open
F133	Alaska geoduck	MOLLU	biv004	small-scale	commercial	North America	United States	SS0115	111	Unspecified UBA	NI	NI	open
F134	Alaska abalone (closed)	MOLLU	gas007	small-scale	commercial	North America	United States	SS0115	NA	hookah, SCUBA	NI	NI	closed
F135	Southern Baja scallop	MOLLU	biv000	small-scale	commercial	North America	Mexico	SS0188	500	hookah	51	108	open

APPENDIX E. SPECIES CODES

Crustaceans (CRUST)

Class	Common Name	Scientific Name	Code
Malacostraca	Crustacean generally	not specified	**crs000**
Malacostraca	Lobster	not specified	**mal000**
Malacostraca	Caribbean Spiny Lobster	*Panulirus argus*	mal001
Malacostraca	Spotted Spiny Lobster	*Panulirus guttatus*	mal002
Malacostraca	Green lobster	*Panulirus gracilis*	mal003
Malacostraca	Ornate rock lobster	*Panulirus ornatus*	mal004
Malacostraca	Red rock lobster	*Jasus edwardsii*	mal005
Malacostraca	Green rock lobster	*Sagmariasus verreauxi*	mal006
Malacostraca	Crab	not specified	**crb000**
Malacostraca	Shrimp/prawns	not specified	**shr000**

Molluscs (MOLLU)

Class	Common Name	Scientific Name	Code
Gastropoda	Gastropod (No ID)	not specified	**gas000**
Gastropoda	Queen Conch aka lambi	*Lobatus gigas*	gas001
Gastropoda	Loco or Chillean abalone	*Concholepas concholepas*	gas002
Gastropoda	Australian greenlip abalone	*Haliotis laevigata*	gas003
Gastropoda	Australian blacklip abalone	*Haliotis rubra*	gas004
Gastropoda	Black Murex Snail	*Hexaplex (Muricanthus) nigritus*	gas005
Gastropoda	Abalone (South Africa)	*Haliotis midae*	gas006
Gastropoda	Pinto abalone	*Haliotis kamtschatkana kamtschatkana*	gas007
Gastropoda	Abalone (No ID)	*Haliotis spp.*	gas008
Gastropoda	Sea snail	*Chicoreus (Phyllonotus) erythrostomus*	gas009
Gastropoda	Keyhole limpets	*Fissurellidae family*	gas010
Gastropoda	Roe's abalone	*Haliotis roei*	gas011
Cephalopoda	Octopus (No ID)	not specified	**cep000**
Cephalopoda	Octopus	*Octopus mimus*	cep001
Cephalopoda	Octopus	*Enteroctopus dofleini*	cep002
Cephalopoda	Mexican four-eyed octopus	*Octopus maya*	cep003
Cephalopoda	California two-spot octopus	*Octopus bimaculatus*	cep004
Bivalvia	Bivalve (No ID)	not specified	**biv000**
Bivalvia	American oyster	*Crassostrea virginica*	biv001

Bivalvia	Peruvian bay scallop	*Argopecten purpuratus*	biv002
Bivalvia	Razor clam	*Ensis arcuatus*	biv003
Bivalvia	Pacific geoduck	*Panopea generosa* (incorrectly called *Panopea abrupta* in the literature 1983-2010)	biv004
Bivalvia	Pen shell	*Atrina spp.*	biv005
Bivalvia	Wrinkled pen shell	*Pinna rugosa*	biv006
Bivalvia	Noble pen shell or fan mussel	*Pinna nobilis*	biv007
Bivalvia	Great Scallop	*Pecten maximus*	biv008
Bivalvia	Pearl oyster spp.	*Pinctada maxima*	biv009
Bivalvia	Geoduck spp.	*Panopea spp.*	biv010
Bivalvia	Pink scallop	*Chlamys rubida*	biv011
Bivalvia	Spiny scallop	*Chlamys hastata*	biv012
Bivalvia	Horse mussel	*Atrina zelandica*	biv013
Bivalvia	Rocky scallop	*Spondylus calcifer*	biv014
Bivalvia	Atlantic deep-sea scallop	*Placopecten magellanicus*	biv015
Bivalvia	Oyster	unsecified oyster spp.	biv016
Bivalvia	Scallop	unspecified scallop spp.	biv017
Bivalvia	Comb pen shell	*Atrina pectinata*	biv018
Bivalvia	Blood clam	*Anadara broughtonii*	biv019
Bivalvia	Soft-shell clam	*Mya arenaria*	biv020
Bivalvia	Mirugai clam	*Tresus Keenae*	biv021

Echinoderms (ECHIN)

Class	Common Name	Scientific Name	Code
Holothuroidea	Sea cucumber (No ID)	not specified	**hol000**
Holothuroidea	Warty Sea Cucumber	*Parastichopus parvimensis*	hol001
Holothuroidea	Pineapple sea cucumber, prickly redfish	*Thelenota ananas*	hol002
Holothuroidea	Black teatfish (sea cucumber)	*Holothuria (Microthele) nobilis*	hol003
Holothuroidea	Giant red sea cucumber or California sea cucumber	*Parastichopus californicus*	hol004
Holothuroidea	North Atlantic sea cucumber	*Cucumaria frondosa*	hol005
Holothuroidea	White teatfish	*Holothuria fuscogilva*	hol006
Holothuroidea	Sandfish	*Holothuria scabra*	hol007
Holothuroidea	(Black) teatfish	*Holothuria whitmaei*	hol008
Holothuroidea	Surf redfish	*Actinopyga mauritiana*	hol009
Holothuroidea	Hairy blackfish	*Actinopyga miliaris*	hol010
Holothuroidea	Prickly redfish	*Thelenota ananas*	hol011
Echinoidea	Sea urchin (No ID)	not specified	**ech000**
Echinoidea	West Indian Sea Egg or Sea Egg	*Tripneustes ventricosus*	ech001

Echinoidea	Green Sea Urchin	*Strongylocentrotus droebachiensis*	ech002
Echinoidea	Chilean sea urchin	*Loxechinus albus*	ech003
Echinoidea	Rock sea urchin	*Paracentrotus lividus*	ech004
Echinoidea	Giant red sea urchin	*Mesocentrotus franciscanus*	ech005
Echinoidea	Kina (sea urchin)	*Evechinus chloroticus*	ech006
Echinoidea	Purple sea urchin	*Strongylocentrotus purpuratus*	ech007
Echinoidea	*H. crassispina*	*Heliocidaris crassispina*	ech008
Echinoidea	*H. pulcherrimus*	*Hemicentrotus pulcherrimus*	ech009
Echinoidea	*P. depressus*	*Pseudocentrotus depressus*	ech010
Echinoidea	*S. intermedius*	*Strongylocentrotus intermedius*	ech011

Fish (FISH)

Superclass	Common Name	Scientific Name	Code
Osteichthyes	Fish (No ID)	not specified	**fsh000**
Osteichthyes	Reef fish (No ID)	not specified	fsh001
Osteichthyes	Pelagic fish (No ID)	not specified	fsh002
Osteichthyes	Ornamental fish (aquarium trade)	not specified	fsh003
Osteichthyes	Parrotfish (No ID)	not specified	**act000**
Osteichthyes	Bumphead parrotfish	*Scarus perrico*	act001
Osteichthyes	Bluechin parrotfish	*Scarus ghobban*	act002
Osteichthyes	Salmon (No ID)	not specified	act003
Osteichthyes	Chilean sheephead	*Semicossyphus maculatus*	act004
Osteichthyes	Atlantic Salmon	*Salmo salar*	act005
Osteichthyes	Tuna (No ID)	not specified	act006
Osteichthyes	Red grouper	*Epinephelus spp*	act007
Osteichthyes	Trout	not specified	act008

Other

Category	Common Name	Scientific Name	Code
Sponge (SPONG)	Sponge (No ID)	not specified	**spo000**
Coral (CORAL)	Coral (No ID)	not specified	**cor000**
	Black coral spp	not specified	**ant000**
Algae (ALGAE)	Kelp (No ID)	not specified	**pha000**
	Kelp	*Nemacystus sp.*	pha001
Shell (SHELL)	Shellfish (No ID)	not specified	**she000**
Tunicate (TUNI)	Tunicates (No ID)	not specified	**tun000**
Unspecified marine living product (MARINE)	Living marine products (No ID)	not specified	**mar000**

Unspecified aquatic living product (AQUA)	Living aquatic/ freshwater products (No ID)	not specified	**aqu000**
Salvage (SALVAGE)	Unspecified salvage	NA	**sal000**

APPENDIX F. MORBIDITY AND MORTALITY METRICS BY FISHERY

Fishery code	Fishery	Number of divers	Reported statistics
F003	Grenada lobster and conch	300	• Eleven incidents of 'bubbles' or 'other symptoms' (represent Type I DCS in local terms) per diver over career (SS0040) • Two incidents of "bends" per diver over career; 63% of divers experienced "bends" in their careers (local terms determined to represent Type II DCS and AGE) (SS0040) • 81% of divers experienced DCI in their careers (SS0040) • 26% of divers reported at least one in their career (SS0040) • 50% of divers (SS0040) • 2.7% diver mortality rate (SS0040)
F014, F015	San Felipe and Rio Lagartos multi-species	525	• 39% diving accident rate (SS0177) • 175 incidents from 1993 to 1996 (SS0177) • 209 recorded DCS incidents per year from 2003 to 2012 (SS0064)
F019	British Columbia commercial geoduck	86	• 0.0024% incidence per dive between 1978-1989 (mostly pre-quota) (SS0093, SS0186) • 0.0093% (pre-quota) and 0.0062% (post-quota) incidence treated DCS per dive (SS0093, SS0186) • 0.0053% (pre-quota) and 0.0015% (post-quota) incidence death per dive (SS0093, SS0186)
F049	Vietnam sea cucumber (Ninh Van and Ly Son Island)	>1,250	• All divers present with DCS symptoms (SS0032) • 0.8% or 800 per 100,000 diver years (pre-intervention); 0.2% or 200 per 100,000 diver years (post-intervention) (SS0032) • 5% or 5000 per 100,000 diver years incidence death or disabling injury such that they can no longer work in the fishery (SS0019) • 0.4% or 400 per 100,000 diver years(pre-intervention); <0.1% or <100 per 100,000 per year (post-intervention) (SS0032)
F051	Chinese dive fishery	>10,000	• 5,278 treated DCI cases over 11 years (February 2000 - December 2010) (SS0092); • 0.13% DCI incidence (SS0092, originally reported by Liu et al 2010 [Article in Chinese]) • 9 fatalities over 11 years (February 2000 - December 2010) (SS0092)
F053	Miskito Keys Caribbean spiny lobster	>700	• 128 DCI incidents from 123 divers or 104% DCI incidence (SS0099) • Two fatalities per 1,000 divers per year or 0.2% fatality incidence per diver per year (SS0099)

F057	Thai Urak Lawoi multispecies	400	• 22.7% spinal injury incidence and 30% joint damage incidence (out of 98 examined divers) (SS0063) • 97.9% of active divers currently experiencing suspected or probable, non-disabling DCI symptoms (SS0063) • 60% of current divers classified as suffering from recurring non-disabling decompression illness (SS0063) • 0.55% incidence disabling morbidity with 5.21% of active and ex-divers experiencing diving-related disabling injuries in their career (SS0063) • 3.0% diving-related fatality incidence and 6.5% total fatality incidence (SS0063)
F063	Turkey sponge and shellfish	NI	• DON incidence of 85.7% in 1985, 52.1% in 1990, and 70.6% in 1996 (SS0187) • DCS incidence of 28.5% in 1985, 25.3% in 1990, and 74.5% in 1996 (SS0187)
F064	Maine scallop	303-366	• 34 divers treated for DCI over 9 years (1989 - 1997) or 1.13% treated DCI incidence (SS0192)
F064, F118	Maine scallop and sea urchin	1207 - 1270	• 0.0731% fatality incidence (SS0192)
F065	Western Australia wild pearl oyster	NI	• 0.01% DCS incidence down from 40% in the 1980s (SS0191)
F077	Nova Scotia sea urchin	NI	• One diving-related fatality over 17 years (1992 - 2008) (SS0050)
F080	Marinduque, Philippines dive fishery	200	• 20 serious, non-fatal DCI cases in 1993 or 10% DCI incidence per diver per year (SS0056) • 10 fatalities in 1993 or 5% fatality incidence (SS0056)
F081	Japanese multispecies	NI	• 28.2% DON incidence (SS0189)
F083	Taiwan dive fishery	NI	• DCS incidence up to 72.6% (SS0196)
F085	Tasmania abalone	NI	• 1.4% DCI incidence (SS0022)
F094, F105	Corn Islands and Puerto Cabezas Caribbean spiny lobster	1,611	• 1,500 disabled divers on the coast due to the diving industry (Dennis, 2003) • Incidents where divers are lost at sea (SS0015)
F105	Puerto Cabezas Caribbean spiny lobster	1,496	• 75-100% incidence of "mild" DCS (SS0015)
F118	Maine green sea urchin	904	• 78% of surveyed divers reported symptoms compatible with decompression illness, pulmonary over-pressurization, barotrauma, and nitrogen narcosis (SS0185) • 10 deaths over 7 years (1992-1998) with a notable decrease after mandatory training and regulation. Three urchin-related fatalities: One involved alcohol (1997), one was from a heart attack (1995), and one resulted from improperly diving under ice (1998) (SS0185) • 0.158% fatality incidence per diver per year (SS0185)

APPENDIX G. RESOURCE STATUS BY FISHERY

Stock status is assigned primarily according to the designation made in the source document. If the original source does not assign a stock status, but provides sufficient information for its designation, stock status is assigned by the author of this study according to the FAO's categories of exploitation (FAO, 2011). The categories are based on stock abundance, not catch per unit effort (CPUE), so reflect total catch, not catch relative to effort. Exploitation categories are defined as follows:

- *Underexploited (under_exp)* – Undeveloped or new fishery. Believed to have a significant potential for expansion in total production;
- *Moderately exploited (mode_exp)* – Exploited with a low level of fishing effort. Believed to have some limited potential for expansion in total production;
- *Fully exploited (full_exp)* – The fishery is operating at or close to an optimal yield level, with no expected room for further expansion;
- *Overexploited (over_exp)* – The fishery is being exploited at above a level which is believed to be sustainable in the long term, with no potential room for further expansion and a higher risk of stock depletion/collapse;
- *Depleted (dep)* – Catches are well below historical levels, irrespective of the amount of fishing effort exerted; and
- *Recovering (recov)* – Catches are again increasing after having been depleted.

Fishery ID	Fishery name	Stock status
F090	Alaska sea cucumber	full_exp
F127	Alaska sea urchin	mod_exp
F133	Alaska geoduck	full_exp
F134	Alaska abalone (closed)	dep
F124	Baja California sea urchin	exp
F087	British Columbia abalone	dep
F019	British Columbia commercial geoduck	full_exp
F017	British Columbia giant red sea cucumber	mod_exp
F016	British Columbia red sea urchin	full_exp

F061	California abalone (closed)	dep
F062	California red sea urchin	over_exp
F093	California sea cucumber	mod_exp
F007	Chagos illegal sea cucumber	over_exp
F095	Chilean multi-species	full_exp
F032	Cook Islands sea cucumber	mod_exp
F094	Corn Islands Caribbean spiny lobster	over_exp
F111	Dominica Caribbean spiny lobster	over_exp
F038	Eritrea sea cucumber	mod_exp, full_exp
F082	Fiji sea cucumber	over_exp
F033	French Polynesia sea cucumber (closed)	Full_exp, over_exp
F114	Haiti Caribbean spiny lobster	over_exp
F104	Jamaica multi-species	over_exp
F039	Kenyan sea cucumber	over_exp
F031	Kiritbati sea cucumber	dep
F040	Madagascar illegal sea cucumber	over_exp
F118	Maine green sea urchin	over_exp
F009	Maldives sea cucumber (diving banned)	over_exp
F027	Marshall Islands sea cucumber (closed)	full_exp
F053	Miskito Keys Caribbean spiny lobster	over_exp
F125	New Brunswick, Canada urchin	mod_exp
F029	New Caledonia sea cucumber	full_exp
F077	Nova Scotia sea urchin	und_exp
F132	Oregon sea urchin	dep
F092	Oregon sea cucumber	und_exp
F030	Palau sea cucumber (closed)	mod_exp
F088	Papua New Guinea rock lobster	full_exp
F021	Papua New Guinea sea cucumber (closed)	over_exp
F105	Puerto Cabezas Caribbean spiny lobster	over_exp
F116	Punta Allen, Quintana Roo Caribbean spiny lobster	full_exp
F025	Samoa sea cucumber	mod_exp
F036	Seychelles sea cucumber fishery	mod_exp, full_exp
F023	Solomon Islands sea cucumber (closed)	dep
F086	South Australia greenlip and blacklip abalone	full_exp
F128	South Korea multispecies	dep
F037	Sri Lankan sea cucumber fishery	over_exp
F112	St. Lucia Caribbean spiny lobster	over_exp
F109	St. Vincent and Grenadines Caribbean spiny lobster	over_exp
F004	Tanzania sea cucumber	over_exp

F028	Tonga sea cucumber (closed)	dep
F113	Turks and Caicos lobster and conch	full_exp
F026	Tuvalu multi-species (closed)	over_exp
F022	Vanuatu sea cucumber	full_exp, over_exp
F049	Vietnam sea cucumber	over_exp
F091	Washington sea cucumber	full_exp
F131	Washington sea urchin	dep
F101	Western Australia abalone	over_exp