Evaluating Spawning Aggregation Management as a Strategy for Conserving Bonefish (*Albula vulpes*) in Cuba

By

Martin Ostrega

Submitted in partial fulfillment of the requirement for the degree

Of

Master of Marine Management

at

Dalhousie University

Halifax, Nova Scotia

TABLE OF CONTENTS

ACKNOWLEDGMENTS iii
ABSTRACT v
LIST OF TABLES vi
LIST OF FIGURES vii
LIST OF ABREVIATIONS viii
1.0 INTRODUCTION 1
1.1 Research Questions and Objectives 3
1.2 Structure of Paper 3
2.0 LITERATURE REVIEW 5
2.1 Why Focus on Fish Spawning Aggregation (FSA) Management? 5
2.2 Important Components to Consider when Selecting FSA Management Options 6
2.3 Cuban Fisheries Management 9
2.3.1 Spatial Management for Fisheries in Cuba 11
2.4 Fish Spawning Aggregation (FSA) Management in Cuba 12
2.5 Why is it Important to Manage Bonefish Spawning Events in Cuba? 14
3.0 WHAT COULD PRAGMATIC BONEFISH MANAGEMENT LOOK LIKE IN CUBA? 17
3.1 Fisheries Scientist Survey Results 17
3.2 Fishing Guides 21
3.3 Fishing Guide and Fisheries Scientists Importance Rankings of Bonefish Fisheries 23
3.4 Management Recommendation Refinement 24
4.0 DISCUSSION 28
4.1 Spatial management for bonefish conservation 28
4.2 The role of LEK in bonefish management 30
4.3 Collaboration 31
4.4 Recommendations 32
5.0 CONCLUSION 34
APPENDIX A: Fisheries Scientist Survey Questions 35
APPENDIX B: Fishing Guide Interview Questions 37
6.0 REFERENCES 39

ACKNOWLEDGMENTS

First and foremost, I must give my sincerest thank you to my supervisors Dr. Megan Bailey and Dr. Aaron Adams, who have provided me the utmost support and contributed significantly to the development of the person and researcher I am today. I can not put into words how much gratitude, respect, and admiration I have for my supervisors, who from the beginning treated me not simply as a student, but as a friend. There were many times where I felt lost and disappointed in myself, and their faith in my abilities, kind and uplifting words, and encouragement helped me complete this project and master's degree. They have had such a strong impact on my life. The level of opportunity and moral support they provided me is truly remarkable and I will always cherish the chance I had to work with such inspirational individuals. Megan and Aaron have always pushed me to believe in myself, ensure I have a healthy work-life balance, spend time fishing and doing other activities that I love. I never could have imagined working with and building such great relationships with these amazing people, who I will forever be grateful to for taking me under their wing.

I also want to extend my gratitude to my advisor Dr. Fabián Pina-Amargós who has helped me immensely throughout the duration of my master's degree. Fabián made this project possible, supported me through the journey, and taught me very much about Cuba. He contributed greatly to this project by providing positive feedback, constructive criticism, and offered himself as an intermediary to interview fishing guides in Cuba and provide data to include in this project. He took the time to provide input to my work, guide me in the right direction, connect me with individuals, and was very kind and generous throughout, for which I am very thankful. I have the utmost respect and admiration for Fabián and will always appreciate his help and involvement in this project.

In addition, I want to give a big thank you to Dr. Jorge Angulo-Valdes and Dr. Kenyon Lindeman for providing incredibly helpful feedback on ideas and answering questions that I had about fisheries management in Cuba. They both helped me greatly and offered time out of their busy schedules to support me through the development and later stages of this project. Furthermore, I would like to give a very sincere thank you to Dr. Steven Cooke for being the second reader for this project. I really appreciate him taking the time to provide comments, suggested changes, and feedback about this project. I am extremely grateful to all these individuals.

I am also beyond thankful to the six incredible Cuban scientists, 16 fishing guides, and five experts who completed surveys and interviews for this project. In addition, I owe a huge thank you to Katia Corral Quijada, who helped translate Spanish and English text for this project. Katia has been one of the greatest collaborators and friends that I have had the pleasure of getting to know and working alongside throughout this degree and I feel very fortunate for our friendship and her support. These are all some of the most generous and kind-hearted people I have had the privilege to communicate with, who offered their support beyond completing surveys and would always make themselves available for questions. I truly feel incredibly fortunate to have connected with these individuals, who helped me in ways I can not describe. All the aforementioned individuals are busy people, but still took the time to provide critical input to my work while asking for nothing in return, for which I am very thankful. Without the help and support from all these people, this project would not have been possible.

In the Bailey Lab, I have been fortunate to work with many remarkable scientists. All these people are incredibly supportive and willing to help one another with any task. I have learned so much being surrounded by such generous and kind individuals, not only about academia, but about life. I have so much respect for every member and have made genuine friendships with many of these incredible people, who I have no doubt will do incredible work for our oceans and fisheries. In addition, I would like to thank Bonefish and Tarpon Trust for supporting me through an internship opportunity and teaching me fundamentals of fisheries science and management in the West Central Atlantic Ocean and Caribbean region. During my master's, I have received financial support from the Sobey Fund for Oceans scholarship and Nippon Foundation Ocean Nexus Program. I would like to give a gracious thank you to those funding bodies.

Lastly, thank you to my partner Yvonne Galos, my sister Jessica Ostrega, and my entire family for their unconditional support. You have all pushed me to complete this project and encouraged me to pursue a project that I am extremely passionate about. Thank you to my parents for giving me the freedom to explore saltwater flats alone and be immersed in the environments that make me feel the most alive. There have been many hours spent worrying if I got attacked by sharks, stingrays, and any other creature a parent can possibly think of, but without this freedom, I would have never developed the love I have for fish and the ocean. Without the support of Yvonne and Jessica, there is no way I would have made it this far. You have both kept me grounded with life outside of school and pushed me to pursue this project. To all of you, I thank you.

ABSTRACT

Ostrega, M., 2021. Evaluating Spawning Aggregation Management as a Strategy for Conserving Bonefish (Albula vulpes) in Cuba. [graduate project]. Halifax, NS: Dalhousie University.

Animals that congregate in large numbers to reproduce in spatially and temporally distinct locations are susceptible to overexploitation. Many fishes form spawning aggregations that are intentionally targeted given high catch rates. Bonefish (*Albula spp*.) species aggregate to spawn, and are culturally and economically important, but generally lack management such as spawning area protections to ensure that fisheries are sustainable. Here, I use Cuba as a case study to develop an improved management strategy for bonefish. Recommendations for the management of bonefish pre-spawning aggregations were based on international experiences, which have been adapted to the Cuban context from results of surveys and interviews with Cuban fisheries professionals and fishing guides. The achievability and feasibility of recommendations were further reviewed by additional experts in the field of fisheries, management, and Cuban policy. The process revealed extensive data-limitations for bonefish fisheries and underscored the importance of including fishing guides, local ecological knowledge, and the context of marine protected areas in Cuba for bonefish management. Recommendations include: 1) initiating information exchange between Cuban management agencies and third-party institutions related to bonefish management; 2) utilizing local ecological knowledge to gather information, formulate management strategies, and enforce regulations; 3) implementing spatial and temporal management measures for bonefish spawning sites; 4) using what is already in place, by protecting spawning sites in the context of existing marine protected areas; 5) collaborating with all stakeholders to manage bonefish spawning sites; and 6) reducing the commercial harvest of the species.

Keywords: Bonefish, Cuba, Spatial Management, Pre-spawning aggregation, Fish spawning aggregation, Migration corridors, Flats fishery

LIST OF TABLES

Table 1: Case studies of different FSA management scenarios that occurred globally. All studies were chose due to having similar socio-economic statuses as Cuba. 8

Table 2: Important aspects to consider when designing bonefish management strategies in the context of the identified challenges, as defined by scientists in surveys. 19

Table 3: Ranking of management measures for effectively conserving bonefish spawning areas in Cuba (1-more effective, 6-least effective). A colour scale from green to brown help depict which management measures were deemed to be the most effective by Cuban scientists. 21

Table 4: Interview results from fishing guides' LEK, indicating general comments and proposed management enhancement strategies for conserving bonefish. 23

Table 5: Experts were asked to assess if each recommendation is achievable, feasible, and representative of Cuban context to evaluate the pragmatism of each strategy. Empty cells indicate that logistical requirements for performing a recommendation may not be feasible or achievable, or additional measures must be considered. Any cell with a "*" indicates that the expert was unsure and suggested seeking further guidance from Cuban experts. 26

Table 6: Challenges identified by experts for the management recommendations presented through the expert elicitation process. 27

LIST OF FIGURES

Figure 1: Cuban fisheries management and governance structure 10

Figure 2: The four geographical marine management zones in Cuba (Puga et al., 2018) 11

Figure 3: A timeline displaying the management actions in Cuba for FSA conservation. Please note, the table stops at 2005 because public data are not available after 2005. Additional FSA MPAs have been developed or are pending approval from the government. 14

Figure 4: The main challenges of researching bonefish spawning events as identified by the surveyed scientists. The base of the pyramid exhibits the greatest challenge, with the level of challenge decreasing up the pyramid. 18

Figure 5: Map outlining the MPAs where guides who participated in interviews work and the two gulfs that have legislation in place to reduce harvest of bonefish and tarpon.. 22

Figure 6: Displaying the importance ranking from scientists and fishing guides of bonefish. C: representing the commercial bonefish fishery; R: recreational bonefish fishery; P: for the people of Cuba; E: economy of Cuba; B for En: bonefish for Cuban ecosystems. 24

LIST OF ABREVIATIONS

C&R	Catch-and-Release
CBD	Convention on Biological Diversity
CIP	The Fisheries Research Center
CITMA	Ministry of Science, Technology, and Environment
CNAP	National Center of Protected Areas
CPNP	Cabo Pulmo National Park
DL164	Decree Law 164/1994
EEZ	Exclusive Economic Zone
ENPFF	National Enterprise for the Protection of Flora and Fauna
FAO	The Food and Agriculture Organization
FSA	Fish spawning aggregation
IUCN	International Union for the Conservation of Nature
JDR	Jardines de la Reina National Park
KMS	Kehpara Marine Sanctuary
MINAL	Ministry of the Food Industry
MINTUR	Ministry of Tourism
MPA	Marine Protected Area
PSA	Pre-spawning aggregation
SDGs	Sustainable Development Goals
SNAP	National System of Protected Areas
TEK	Traditional ecological knowledge
ZBREUP	Zones Under Special Regime of Use and Protection

1.0 INTRODUCTION

Global biodiversity loss, which can be attributed to direct and indirect impacts from anthropogenic disturbances, is one of humanity's most pressing contemporary environmental issues (IPBES, 2019). For marine environments, recurring management failures and declines of living oceanic resources have prompted societies to demand alternative management actions in many regions of the world (Sobel and Dahlgren 2004), including the Caribbean (Angulo-Valdes, 2005). In the Caribbean, societies rely on living marine resources (e.g., fish) for subsistence, cultural purposes, ecological services, and economic opportunities (Sadovy de Mitcheson et al. 2013). Fisheries are amongst the most in need of effective management since the overexploitation and decline of fish populations have negative impacts on societies, economies, and environments (Hughes, 2020).

Fisheries are characterized as commercial, small-scale, artisanal, traditional, and recreational (UN Atlas of the Oceans, 2016). Of particular importance in the Caribbean Sea are recreational fisheries that contribute hundreds of millions of dollars to the region (FAO, 2016). Management and conservation are required to ensure fisheries and their associated economies are sustainable. One of the most economically valuable recreational fisheries in the Caribbean is the flats fishery, which is mostly catch-and-release (C&R), comprised of four target species: Tarpon (*Megalops atlanticus*), Permit (*Trachinotus falcatus*), Common Snook (*Centropomus undecimalis),* and Bonefish (*Albula vulpes*) (Figueredo-Martin et al., 2010; Adams, 2017).

The flats fishery has an annual economic impact of US$456 million in Florida USA (Fedler, 2013), US$169 million in The Bahamas (Fedler, 2019), US$56 million in Belize (Fedler, 2014), and US$45 million in Mexico (Palomo and Perez, 2021). This fishery maintains local livelihoods by providing well-paying jobs that are directly linked to the tourism industry, with additional jobs in transport, logistics, and hospitality (Figuredo-Martin et al., 2010). The economic value of the flats fishery should provide leverage for developing sustainable management measures, which safeguard critical fish habitats and life-cycle events, such as fish spawning aggregations (FSAs) (Erisman et al., 2015; Adams et al., 2021).

FSAs are large gatherings of conspecific fish that meet predictably and repeatedly for the purpose of reproduction (Gonzalez-Bernat et al., 2020). For many species, FSAs occur in locations separate from habitats used during non-spawning times and these events are crucial for replenishing fisheries and sustaining fish populations (Erisman et al., 2015). However, aggregation-spawning, may lead to population-level collapse if exploitation at the FSAs is uncontrolled (Sadovy de Mitcheson and Erisman, 2012). FSAs are regularly targeted and overexploited, as fishers can harvest the largest number of fish with the least amount of effort (Gonzalez-Bernat et al., 2020). For example, in Mexico, fishers harvest more than 2 million individuals (5000 tonnes) of Gulf Corvina (*Cynoscion othonopterus*) in <30 days at a single FSA site (Erisman et al., 2015). Overfishing at FSAs can lead to population collapse, alterations to population structure (e.g., shifts in adult sex ratios or mean body size), habitat degradation, disturbance to food-web dynamics, and can have additional negative socio-economic and environmental implications (Hamilton et al., 2011; Gruss et al., 2014).

Management of FSAs is largely dependent on spatial and temporal identifications of spawning events (Erisman et al., 2015). Spatial and temporal management strategies are regularly developed for single-species and multi-species aggregations that are threatened by overfishing (Sadovy de Mitcheson and Erisman, 2012), with numerous benefits, including higher catches at non-aggregation times and over the long-term (e.g., Giant Sea Bass and White Seabass recovery in California) (Pondella and Allen, 2008). Moreover, enforcement can be relatively effective because FSAs are limited in time and space (Russell et al., 2014; Sadovy de Mitcheson and Erisman, 2012). Thus, the management of spawning aggregations can be a logistically feasible and economically practical strategy for conserving fisheries for species with FSAs (Russell et al., 2012).

Although 12 species of bonefish have been identified worldwide, of which four species occur in the Caribbean, the species (*Albula vulpes*) that supports the flats fishery in the Caribbean is listed as Near Threatened on the IUCN Red List, due to habitat loss and fragmentation, coastal development, declines in water quality, and harvest by commercial, artisanal, and recreational fisheries (Adams et al., 2013). Bonefish are especially vulnerable during their reproductive phase because they form large aggregations (>5000 individuals) in spatially and temporally distinct locations (Danylchuk et al., 2011; Adams et al., 2019; Danlychuk et al., 2019), so are susceptible to harvest and habitat loss. Near full and new moons between October-April (identified spawning season in the Bahamas), bonefish migrate from their home ranges to shallow protected bays immediately adjacent to deep water, where they form pre-spawning aggregations (PSAs) that may last one to five days (Adams et al., 2019). Bonefish move offshore at dusk where they have been documented descending to >137m to spawn, and following spawning, they return to their original home ranges (Lombardo et al., 2020). As with other species that migrate to spawn as part of FSAs, bonefish are vulnerable during migrations, while in PSAs, and during spawning with potential far-reaching population implications (Erisman et al., 2015; Pittman and Heyman, 2020).

Despite the economic importance of the recreational bonefish fishery in Cuba, management measures are not in place to conserve the species during spawning migrations and aggregations (Rennert et al., 2019). Since Bonefish are intensively harvested at multiple PSA sites and during spawning migrations in Cuba, implementing fisheries management strategies may help to ensure this species can reproduce successfully (Angulo-Valdes et al., 2017). The current limitations for managing FSAs could hinder Cuba from achieving its sustainability and environmental protection goals (Gerhartz-Muro et al., 2018; Claro et al., 2019). Therefore, the purpose of this research is to propose pragmatic management strategies for bonefish spawning events and locations to benefit communities, the economy, and environments and ensure fishery sustainability in Cuba.

1.1 Research Questions and Objectives

The objectives of this research are to:

1. Develop management strategies for bonefish spawning aggregations in Cuba, by providing recommendations that are feasible, achievable, and respectful of local context
2. Emphasize the importance of incorporating and considering bonefish in fisheries and spatial management plans

These objectives were addressed with a main research question and two sub-questions:

1. What are successful approaches for managing FSAs globally, and how can those be applied to bonefish PSAs in Cuba?
    a. What tools are available in Cuba for managing fisheries, and how can those tools be applied to the bonefish fishery, specifically the management of PSAs and spawning migrations?
    b. What is known about bonefish fisheries in Cuba and what are the management needs for the species?

1.2 Structure of Paper

The introductory chapter states the purpose of the research, research questions and objectives, and explains the focus of this study. Chapter 2 presents the methods and results of a literature review, which explores the significance of FSA management, examines successful global FSA management strategies, and discusses a few case studies from other countries that have similar socio-economic and environmental contexts as Cuba. This chapter also reviews Cuban fisheries management tools and the challenges and opportunities for managing bonefish spawning events in Cuba.

Chapter 3 describes the methods and results of empirical data collection and analysis, including surveys, interviews, and expert elicitation. Processes discussed include the use of surveys to gain insight into Cuban fisheries management and fishing guides' Local Ecological Knowledge (LEK) about bonefish, and the expert elicitation process. Through surveys and interviews, management recommendations are developed, which are deemed to be feasible, achievable, and representative of Cuban context.

Chapter 4 synthesizes insights from the multiple study components employed in this research to support management recommendations for managing bonefish spawning and the inclusion of public participation. The final chapter concludes the study and presents the main take-away points.

2.0 LITERATURE REVIEW

Peer-reviewed scientific journals, book chapters, and peer-reviewed reports focused on global fish spawning aggregation (FSA) management approaches and fisheries management in Cuba were utilized for the literature review. Keywords for the first portion of the literature review were "fish spawning aggregation" AND "management"; for the second portion, "fisheries management" AND "Cuba", which were entered into *Scopus* in English on July 2021 to generate articles. For each portion, abstracts from peer-reviewed publications that included these key words were screened to determine relevance to the project. Additional reports that provided useful information were found through bibliographic searches (snowballing) of relevant sources. Articles that passed screening were then read in full.

2.1 Why Focus on Fish Spawning Aggregation (FSA) Management?

Because of its importance to population sustainability for species with ecological, social, and economic importance, the reproductive process should receive special management attention (Erisman et al., 2015; Pittman and Heyman, 2020). However, FSA management has been hindered by the belief that conventional fisheries management (e.g., catch quotas, size limits, gear restrictions, etc.) obviates the need for focussing on spawning aggregation site conservation (Tobin et al., 2013). Management of predictable, productive, and critical spawning events can provide large, rapid, and measurable benefits for sustainable fisheries management in a way that is logistically feasible, and economically practical (Erisman et al., 2015). The effective protection of FSAs from overexploitation has enormous value to local communities, as depleted stocks can be rebuilt and fisheries sustainability can be achieved (Hamilton et al., 2011; Aburto-Oropeza et al., 2011).

Though not fully understood due to data limitation challenges, the ecological importance of FSAs is clear (Erisman et al., 2015). As eggs and sperm are ejected during spawning, ocean currents generate intermittent upwellings and localized gyres, which retain massive volumes of nutrients (Ezer et al., 2011). Spawning events create 'egg boons', which are temporary concentrations of highly nutritious fatty acids (molecules that are vital for marine animal and ecosystem health), which create hotspots of primary and secondary productivity that cascade into coastal and pelagic food-webs (Erisman et al., 2015; Morato et al., 2010). Interrupting spawning events may result in an 87% reduction in nutrient supplies to various species and habitats (Archer et al., 2014). Protection of FSAs can have an umbrella effect for supporting food-web dynamics and populations of apex predators, marine megafauna, and other marine species, which are necessary for maintaining healthy ecosystem functions (Heyman et al., 2001; Erisman et al., 2015). Ephemeral concentrations of food resources found at FSA sites attract a wide diversity of large, migratory predators and mega-planktivores (e.g., sharks, billfishes, whale sharks, and manta rays), and mismanagement of FSAs can contribute to the losses of many species and global declines in ecosystem health (Burke and Maidens, 2004; Nemeth et al., 2010).

Spatially and temporal distinct FSAs present opportunities to scale down monitoring, enforcement, and research and streamline efforts accordingly to produce measurable benefits for fisheries (Heyman, 2014; Erisman et al., 2015). Proper management of FSAs can replenish fish populations at larger scales, by increasing fish biomass at protected sites and producing spillover of juveniles and adults into adjacent fishing areas, which benefits many stakeholders (Erisman et al., 2018). The prevalence and persistence of FSAs can help determine the health of marine ecosystems and serve as baselines to assess the status of other areas (Sadovy de Mitcheson and Domeier, 2005). For areas lacking data to conduct robust stocks assessments, focussing efforts first on FSA management will provide the highest benefit to cost ratio for fisheries and conservation outcomes (Erisman et al., 2015).

Despite the importance of FSAs for food security and fisheries productivity, very few fisheries management strategies acknowledge the importance conservation of these events (Claro et al., 2019). However, FSA conservation has great potential to address multiple existing global sustainable ocean policy targets (Pittman and Heyman, 2020). FSAs are prime candidates for recognition as *Areas of Particular Importance for Marine Biodiversity* and *Ecologically or Biologically Significant Areas* because of their high susceptibility to degradation and their significant contribution to sustainable fisheries (CBD/WG2020/2/3, 2020; Pittman and Heyman, 2020). The Food and Agriculture Organization (FAO) Code of Conduct for Responsible Fisheries recommends protection and rehabilitation of all critical fisheries habitats in the 2030 Agenda for Sustainable Development outlines Sustainable Development Goals (SDGs): Target 2 (end hunger, food security, improved nutrition, and sustainable agriculture), Target 14 (life below water), and Target 17 (partnerships), which the protection and management of FSAs would contribute towards (FAO, 2005). In addition, Targets 6 (recover depleted fish stocks) and 11 (conserving areas of importance for biodiversity and ecosystem services) of the Aichi Biodiversity Targets of the Convention on Biological Diversity (CBD) would also be addressed if FSAs are effectively managed and receive appropriate spatial protection (CBD/WG2020/2/3,2020).

2.2 Important Components to Consider when Selecting FSA Management Options

The tools and strategies used as management and conservation options for aggregations vary widely (Russell et al., 2012), as outlined in four case studies (Table 1). Deciding upon appropriate management strategies to produce tangible results would entail that immediate short-term and long-term socio-economic and ecological conditions are considered for each location and species (decisions are best made on a case-by-case basis) (Sadovy de Mitcheson, 2009). Feasible and suitable management options can then be determined and implemented based on what is economically and logistically feasible. FSA management tools include species-specific protection (export, sale, or possession of species may be restricted seasonally or year-round), temporal and spatial protection (specific geographic locations may be closed to fishing or entry seasonally or permanently), and fishery input and output controls (catch quotas, limited entry to a fishery, or gear restrictions) (Russell et al., 2012). Since data are lacking for many aggregation-related fisheries, precautionary and adaptive management are necessary and should be embraced by many states that continue to allow fishing at FSAs (Sadovy de Mitcheson, 2016).

Since many fish are targeted during and outside of aggregating periods, single management measures alone are likely to be insufficient for conserving species when spawning (Russell et al., 2012). This is especially true for transient spawners – those that migrate far distances from home-ranges for the purpose of spawning – as overfishing may occur along migration routes or in other areas where fish are vulnerable to human disturbance (Claro et al., 2019). Coupling management strategies directed at protecting spawning aggregations with additional measures placed on non-aggregation components are considered most effective in sustaining aggregate species (Sadovy de Mitcheson and Eklund, 1999; Russell et al., 2012). Rhodes and Warren-Rhodes (2018) describe several critical factors to consider when designing management strategies that rely on spatial and temporal closures/bans: (1) managers must understand the spawning seasons for FSA species; (2) site-based scientific and local monitoring and data analysis must evaluate management efficacy or need for improvements; (3) frequent enforcement (community or political institution) is requisite. Where enforcement is an issue, multiple management measures should be complementary of each other (Russell et al., 2012).

One particular case study, that of Tarawa Atoll in Kiribati, demonstrated the necessity for local ecological knowledge (LEK) to be integrated into management for FSAs, as ignoring LEK could lead to inadequate decision-making (Johannes et al., 2000). Additional studies concluded that management options must be determined with the participation of local stakeholders who could be impacted by decision-making (Miller et al., 2018). Fishers or local marine users can provide critical information on interannual, seasonal, lunar, diel, tide-related, and habitat-related differences that influence fishing strategies, which is paramount when determining management options (Johannes et al., 2000). If LEK is considered and trusting relationships are built with local stakeholders, local buy-in and compliance to management will be greater and opportunities for co-managing marine spaces can help achieve mutual conservation objectives (Filous et al., 2019).

Co-management of spawning events may be essential in areas that lack sufficient national resources and should be considered for FSA conservation (Hamilton et al., 2012). For example, the collaborative efforts of combining LEK and science led to the establishment of a 2-year community-based

Table 1: Case studies of different FSA management scenarios that occurred globally. All studies were chosen due to having similar socio-economic statuses as Cuba and can be used as guidance when creating management recommendations.

RED HIND IN THE US VIRGIN ISLANDS (Nemeth, 2005)	**THREE SPECIES OF GROUPER IN POHNPEI (Rhodes, 1999)**
Problem: Red hind were intensively overfished at a spawning aggregation site, which impacted the national population greatly. **Management response:** A 41km^2 permanent no-take MPA was developed to protect a spawning aggregation for this species. Tag-and-release fishing and fish transects were used to monitor the site for 5 years. **Results:** The maximum total length of male red hind increased by nearly 7 cm following permanent closure. Furthermore, the average density and biomass of red hind increased by over 60% (a 3-fold increase from 26,200 to 84,000 individuals) in 3 years of protection. Protection of the FSA site also contributed towards increasing overall size of red hind caught in the commercial fishery, which increased the value of the grouper fishery for local fishers. **Lessons learned**: FSA management led to larger more valuable individuals.	**Problem:** Decreasing grouper populations (from overfishing) at spawning aggregations; however, precise dimensions of the spawning area were unknown. **Management response:** A marine reserve – Kehpara Marine Sanctuary (KMS) – was established to protect spawning stocks. Spatial and temporal dimensions fell short of protecting two of the three species that formed FSAs adjacent to KMS. **Results:** FSA overfishing persisted, and one of the two unprotected aggregations experienced a 20%-30% decline of fish abundance. Following scientific surveys, KMS's boundaries were revised to include previously unprotected FSAs with an additional buffer zone for added protection from fishermen. Boundaries were insufficient for protecting other vulnerable spawning-related events (e.g., migratory pathways), and populations failed to recover. **Lessons learned**: Adaptive management of spatial measures necessary to achieve effectiveness.
BONEFISH OF TARAWA ATOLL, KIRIBATI (Johannes et al., 2000)	**RECOVERY OF FISH BIOMASS IN CABO PULMO NATIONAL PARK, MEXICO (Aburto-Oropeza et al., 2011)**
Problem: Gill nets and traps targeting bonefish pre-spawning aggregations and migration routes contributed to drastic population declines of the species in the area, which was the most important food fishery for locals. **Management response:** Fisheries Department failed to collect adequate information about spawning areas, their vulnerability, and importance. Instead, Johannes and Yeeting (2000) conducted interviews with experienced fishermen and acquired vital LEK about the fishery. This led to the establishment of local marine tenure to allow for the protection of spawning runs. **Results:** Locals reported that catch-per-unit-effort and average bonefish size were increasing, as LEK allowed for traditional users to realize that bonefish stocks needed to be replenished and management was conducted by community members to sustain this vital resource. **Lessons learned:** LEK and local tenure can promote FSA conservation.	**Problem:** Overfishing at FSAs led to extensive depletion of fish populations in Cabo Pulmo (CPNP). **Management response:** A 71km^2 no-take marine reserve was developed to protect FSAs and important habitats. Furthermore, there was strong social cohesion, community leadership, and effective enforcement established for the park. **Results:** Five years after, total fish biomass increased by 3.49 t ha^{-1} (or 463%) and biomass of carnivores and top predators increased by 4 to 11 times, respectively. The recovery of fish biomass has resulted in significant economic benefits, for instance, thousands of divers are attracted to witnessing spawning aggregations within CPNP, which generates millions of dollars for the surrounding community each year. **Lesson learned**: Community managed MPAs are viable solutions to fishery collapse caused by overfishing FSAs.

underwater monitoring program at the largest known FSA in Roviana Lagoon, Soloman Islands to develop community-based MPAs that safeguard reproduction for three grouper species (Hamilton et al., 2012). Additionally, Filous et al. (2021) demonstrated that increases in spawning potential for a culturally important bonefish (*Albula glossondonta*) stock in French Polynesia was due to recognizing local management systems, incorporating fisheries research, youth education, and development of a locally managed marine area. Thus, education, LEK, and public participation for determining management solutions that conserve FSAs must be prioritized by resource managers to ensure compliance and support from local stakeholders.

2.3 Cuban Fisheries Management

Some of the most well-preserved marine and coastal ecosystems in the Caribbean are found within the national jurisdiction of Cuba (Kritzer et al., 2014). Around the island, various fishing activities (commercial, recreational, and subsistence fishing) providing employment, food, and income to residents (Miller et al., 2018). All production and management of fishery resources are controlled and developed by The Ministry of the Food Industry (Ministrio de la Industria Alimentaria, or MINAL) (Puga et al., 2018). Fisheries are managed under a centralized system and rulemaking involves the Directorate of Fisheries Regulations and MINAL (MINAL, 2015). The National Fisheries Commission is made up of several agencies and organizations in Cuba that discuss fisheries-related topics and needs in the country. The scientific branch of MINAL is The Fisheries Research Center (CIP), which is responsible for developing necessary technical support for fisheries management and proposing regulations to the Directorate of Fishing Regulations (Puga et al., 2018). Once regulations are approved, they are submitted to the Minister of MINAL, and approved regulations are published by decree law and controlled by the National Inspection Office (Puga et al., 2018). Decree laws outline policies and regulations for managing marine resources in Cuba, such as fisheries (Figure 1) (Gerhartz-Muro et al., 2018).

The main fishing resources are finfish (58% of landings) and spiny lobster (20% of landings and accounts for 75% of the country's revenues from fishing) (Garcia, 2014). The Cuban fishing sector includes the state-owned industry, which operates 35 ports and employs around 14,000 people (MINAL, 2015). All invertebrate and 90% of finfish catches come from state-owned vessels (Puga et al., 2018). In addition, the private sector operates 196 fishing bases, comprised of 18,638 private commercial fishers and 17,657 private non-commercial fishers (Miller et al., 2018). Private commercial vessels must be under a strict contract regime with the state enterprise to be granted permission to fish within any of the four Cuban marine management zones (Puga et al., 2018) (Figure 2).

Fisheries in Cuba were considered under-exploited until the mid 1960s (Claro et al., 2009; Baisre, 2017), but several species were overfished due to increases in fishing effort, introductions of motorized boats, large-scaled fishing gears, and inadequate fishing regulations by the 1970s, (Claro et al., 2009). The species that were severely overexploited in Cuba include lane snapper (*Lutjanus synagris*), mullets (*Mugilidae*), Nassau grouper (*Epinephelus striatus*), the queen conch (*Strombus gigas*), and shrimp (Claro et al., 2001). Many of these species were fished at their spawning aggregations (Claro et al., 2009). Today, 5% of fishery resources have collapsed, 20% are fully exploited, and 74% are overexploited (Baisre, 2017). To address over-fishing, regulations were introduced such as closures, limits to fishing effort and quotas, and fishing effort was redirected towards targeting under-fished species (e.g., stingrays, mojarras, porgies, Atlantic thread herring, clams, crabs, and others) (Baisre, 2000; Claro et al., 2001; Claro et al., 2009). Recommendations have been made to update fisheries policies and regulations to reduce fishing effort and develop sustainable fishing strategies (Baisre, 2017).

Cuba has robust fisheries laws, which aim to reduce illegal fishing, replenish declining fish stocks, and provide jobs (EDF, 2019). In addition, Decree Law 164/1994 (DL164) establishes the authority for implementing harvest controls in marine fisheries, and adoption of Zones Under Special Regime of Use and Protection (ZBREUP) (Gerhartz Muro et al., 2018). ZBREUP is a spatial tool for fisheries management that is a precursor of the establishment of MPAs (Consejo de Estado, 1996). A recently implemented law is the Cuban Fisheries Law (2020), which mandates science-based, adaptive management approaches for conserving fisheries (EDF, 2019). With this law, Cuba is expanding the use of methods to manage data-limited fisheries,

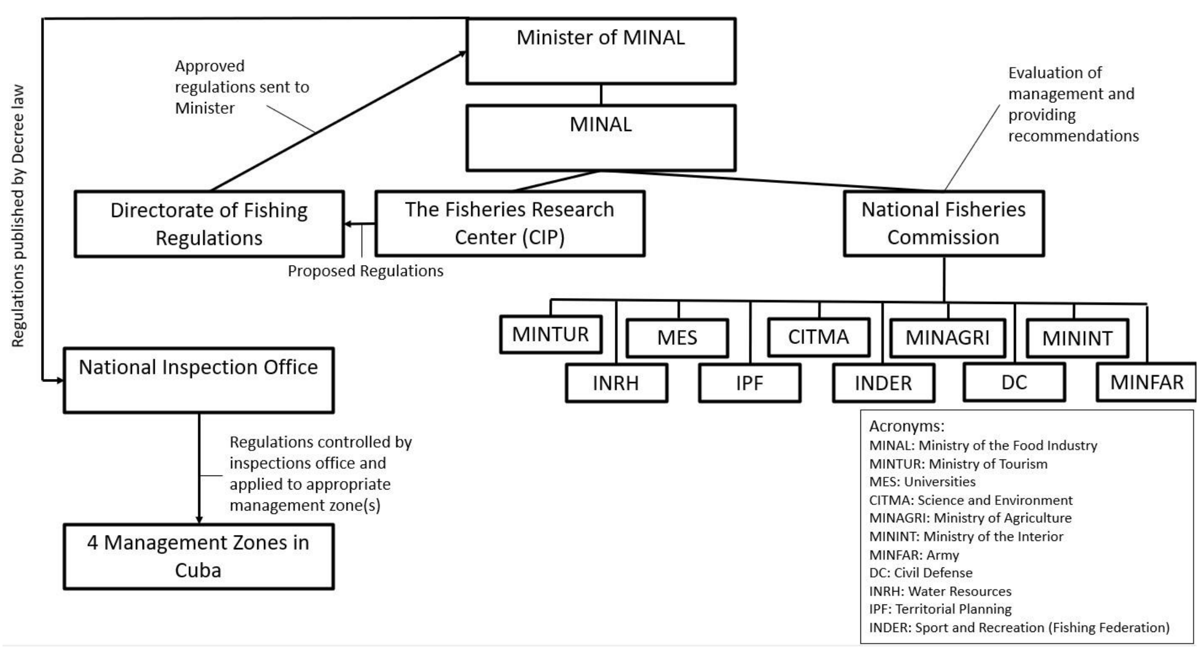

Figure 1: Cuban fisheries management and governance structure

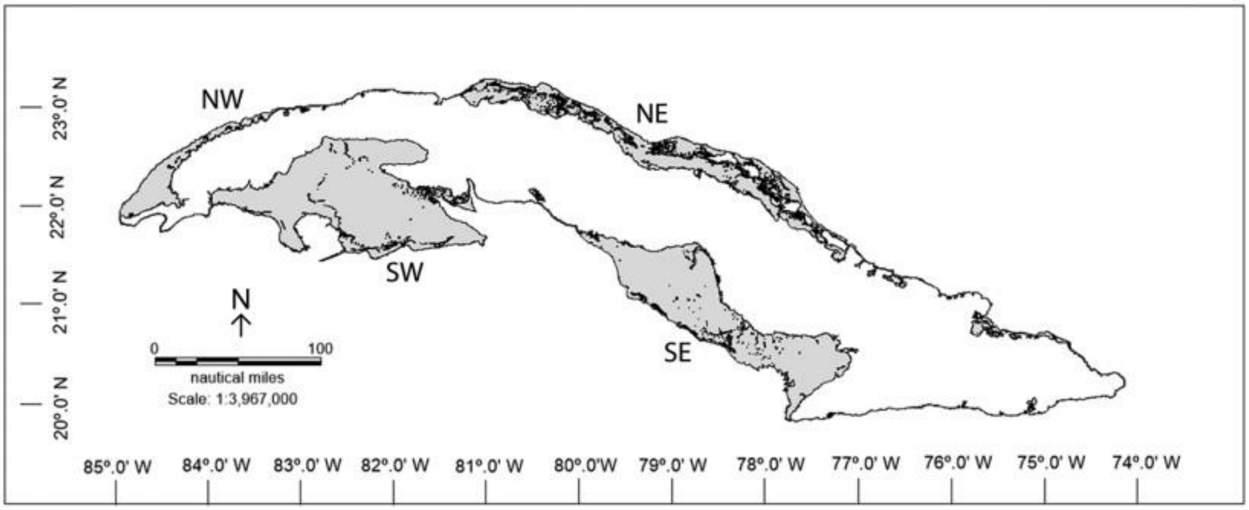

Figure 2: The four geographical marine management zones in Cuba (Puga et al., 2018)

developing new licensing and management frameworks for private commercial fishers, and those who want to transition into the recreational fishing sector, while preventing overfishing (EDF, 2019). Currently, fishery managers utilize ecosystem-based management tools, regulations, and spatial management tools, such as fishery reserves and Marine Protected Areas (MPAs) to conserve essential fish habitats (Garcia, 2014).

2.3.1 Spatial Management for Fisheries in Cuba

Cuba is ahead of many coastal nations for designating marine and coastal protected areas, as approximately 25% (ca. 1,744,390 ha) of the Cuban shelf region is spatially protected (CNAP, 2013). Cuban MPAs incorporate developed planning structures, with management objectives that include biodiversity and socio-economic factors (Perera-Valderrama et al., 2018; Claro et al., 2019). Within MPAs, the harvest of highly regulated spiny lobster, catch-and-release (C&R) recreational tourism fishing, and SCUBA diving are allowed, where resources can support such activities (Angulo-Valdes et al., 2017). MPAs are under the coordination of the National Center of Protected Areas (CNAP), with many co-managed by the National Enterprise for the Protection of Flora and Fauna (ENPFF) (Perera-Valderrama et al., 2018; Claro et al., 2019). MPAs are a subsystem of the National System of Protected Areas (SNAP), where SNAP is administered by CNAP within the Ministry of Science, Technology and Environment (CITMA) (Puritz, 2017).

Difficulties are encountered with compliance and scientific monitoring in MPAs, as resources are limited, and threats such as illegal fishing, overfishing, invasive species, and climate change are ever-present (Angulo-Valdes et al., 2017). Zoning strategies aid Cuban officials with allocating resources towards monitoring and enforcement in certain areas and are originally derived from the ZBREUP (Puritz, 2017). Zones include conservation, diving, C&R fishing, no-touch, monitoring, and control zones, and areas for boat mooring or lobster-fishing (Puritz, 2017). Efforts are made to conserve more-vulnerable habitats or species by distinguishing between areas that need more protection, monitoring, or enforcement (Whittle, n.d.). For example, areas designated as C&R fishing zones are frequently patrolled by fishing guides and their presence can deter illegal poachers; however, certain no-touch zones may receive minimal compliance monitoring, as these areas could be secluded and hard to access (Santella, 2019).

MPAs are greatly affected by the ecological, social, economic, and political contexts of the surrounding coastal areas (Cicin-Sain and Belfiore, 2005). MPAs that incorporate fisheries or tourism activities regularly outperform their counterparts (Puritz, 2017; Perera-Valderrama et al., 2020). One way this performance happens is through financial contributions from ecotourism and private-public partnerships, which can be reinvested into park management, enforcement, and research, ultimately contributing to safeguarding marine ecosystems within MPA boundaries (Puritz, 2017). Jardines de la Reina (JDR) Marine Reserve, for example, has a tourism diving and fishing fleet established, which contributes the greatest to park revenues (Global Conservation, 2020). The eco-tourist hotel and fleet in the park is the *Avalon Cuban Diving/Fishing Centers* (an Italian ecotourism company that is involved in a public-private partnership with Marlin Nauticas y Marinas, the Cuban government's agency responsible for overseeing Cuba's marine-based tourism) (Puritz, 2017). This fleet permits 2,000 divers and 1,000 recreational fishermen to visit annually, which generates around USD $10 million (Global Conservation, 2020). Additionally, the park seeks to protect critical population sites for prominent fisheries that hold major ecological and economic significance, such as species that aggregate to spawn (CNAP, 2013). Although JDR is a prime example, other MPAs in Cuba incorporating C&R fishing have similar positive impacts; however, studies on those areas have not been published (Perera Valderrama et al., 2017).

2.4 Fish Spawning Aggregation (FSA) Management in Cuba

Fish spawning aggregations (FSAs) in Cuba are vital for supplying reproductive outputs to all Cuban regions, as well as the Caribbean region, including Cayman Islands, Hispaniola, Nicaragua, Jamaica, Colombia, Honduras, Belize, Mexico, Florida, Turks and Caicos, and The Bahamas (Pina-Amargos et al., 2021). However, to date, few management measures have been developed for FSAs specifically in Cuba (Figure 3), and FSAs that form within the national jurisdiction of Cuba are regularly targeted by fishers (Claro et al., 2001; Claro and Lindeman, 2003). Some stocks remain overfished during spawning aggregation periods, and some have collapsed all together (Sadovy de Mitcheson et al., 2012). Between 60%-70% of annual catches of lane snapper are obtained during a 10–12-day period when spawning is at its peak (Baisre, 2017). Moreover, the collapse of Nassau grouper and mullet in Cuba was due to overfishing at FSAs (e.g., Nassau grouper catches reached 1700 tonnes in 1959, and today, few viable FSAs of this species persist in Cuba) (Baisre, 2017; Claro et al., 2009; Claro et al., 2019).

Although management actions have been implemented for FSAs in Cuba, their effectiveness are rarely evaluated (Claro et al., 2019). In Cuba, few MPA management plans address spawning conservation or management efficacy (Claro et al., 2019). Yet, spawning aggregation conservation has been emphasized to contribute to sustainable fisheries goals in the country (Claro et al., 2009; Baisre, 2018; Claro et al., 2019). For example, Horta e Costa et al. (2020) argue that Cuba's most-valued commercial fisheries (e.g., snappers) are not benefitting from adequate MPA protection. FSAs are being left out of some Cuban MPAs, despite the recognition that spawning sites should be considered when designing MPA networks (Claro and Lindeman, 2003; CNAP, 2013; Horta e Costa et al., 2020). Notably, the protection of spawning biomass and FSAs can contribute to positive MPA effects if boundaries incorporate migration routes and are large enough to encompass fish life-history phases (e.g., home ranges, nursery habitats, and FSAs) (Angulo-Valdes and Hatcher, 2013; Claro et al., 2009). For example, JDR encompasses FSAs and species' home-ranges, which contribute toward positive spillover effects to areas beyond the MPA boundaries; however, a smaller MPA like Punta-Frances does not adequately encompass vulnerable spawning sites, and species continue to be overfished when spawning (Pina-Amargos et al., 2010; Angulo-Valdes and Hatcher, 2013). Rezoning, development of monitoring programs, and the establishment of temporal closures within and beyond MPAs are proposed strategies for sustaining FSAs in Cuba (Horta e Costa et al., 2020). For commercially important species' FSAs that have been identified, 62% have protected area status; however, the effectiveness of protection is variable (Claro and Lindeman, 2003; Perera-Valderrama et al., 2020). Outside of commercially important species, very few FSAs have been identified for recreationally important species, which do not receive specific forms of protection (Angulo-Valdes et al., 2017).

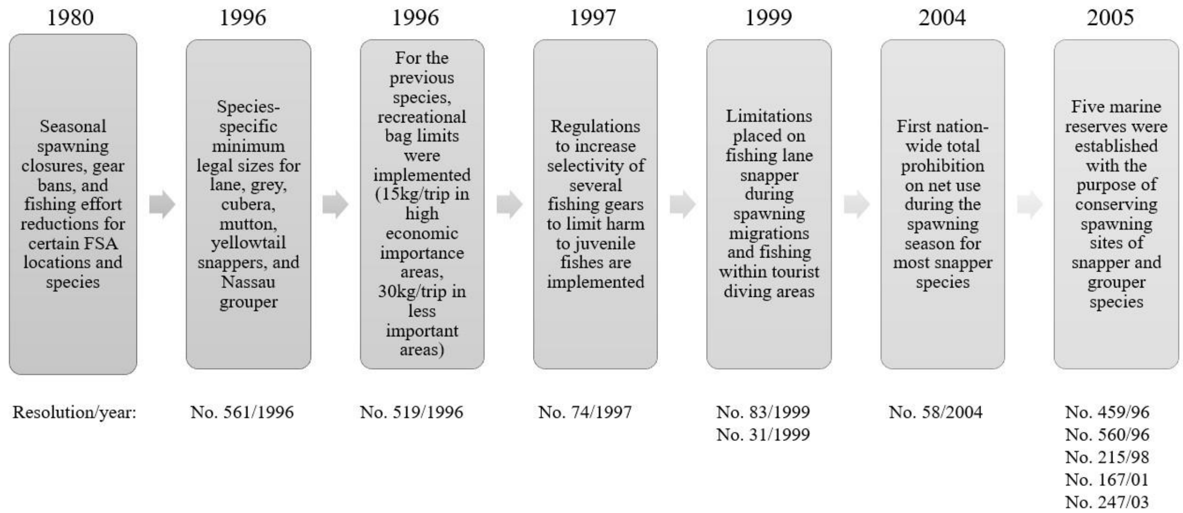

Figure 3: A timeline displaying the management actions in Cuba for FSA conservation. Please note, the table stops at 2005 because public data are not available after 2005. Additional FSA MPAs have been developed or are pending approval from the government (Lindeman personal communication, 2021).

2.5 Why is Fisheries Management Important for Bonefish Spawning Events in Cuba?

Bonefish typically exhibit high home range fidelity in shallow tropical and sub-tropical sand, marl, seagrass, mangrove and hardbottom coastal flat environments and play an important role in their ecosystem food chain (Adams et al., 2019; Boucek et al., 2019). As predators, they control crustacean and smaller fish populations. As prey, they support predators such as sharks and barracuda with a steady food source (Bruger, 1974; Snodgrass et al., 2008). This species is polygynandrous - mating without an individual chosen partner in deeper water by broadcast spawning, where females and males simultaneously eject eggs and sperm into the water column (Danylchuk et al., 2011). Furthermore, Bonefish FSAs and networks offer great potential as conservation bright spots to rehabilitate marine ecosystems, replenish fished populations, and ensure flow of ecosystem services to the many people and species who rely on them for their wellbeing (Pittman and Heyman et al., 2020; Santella, 2019).

Spatial management tools such as MPAs are important for conservation and sustaining vital socio-economic industries, such as the flats fishery in Cuba (Angulo-Valdes et al., 2017). In Cuba, bonefish populations are declining from overfishing at spawning sites (Angulo-Valdes et al., 2017). Set nets or pens (*tranques or corrales*) are deployed perpendicular to the coast to intercept migrating spawners (Claro et al., 2001), and additional gill netting at PSAs removes thousands of fecund individuals (Angulo-Valdes et al., 2017). One pre-spawning aggregation (PSA) in Boca de Manati-Turiguano, is targeted by commercial fishers who deploy gill nets (800 meters long, 40 mm mesh size) to harvest over 20 tonnes of bonefish per season (Angulo-Valdes et al., 2017). Harvested bonefish are then used as bait for long lines, sold in the black and legal markets, grounded for animal feed, or used for personal consumption (Santella, 2019). The pressures on bonefish spawning aggregations are substantial; however, no data are available to quantify the impacts on bonefish or ecosystems more broadly (Angulo-Valdes et al., 2017).

A principal feature of MPAs in Cuba is to protect critical populations for species of high economic and conservation priority (CNAP, 2013; Claro et al., 2019). Bonefish spawning migration corridors and PSAs meet this criterion (Claro et al., 2019). The significant economic value of the bonefish recreational fishery in Cuba should provide leverage for instigating management actions to protect vulnerable life-cycle events, such as spawning (Santella, 2019). Recent estimates of larval transport from known and suspected spawning locations in the Caribbean Sea suggest that Cuba plays a central role in regional population connectivity (Zeng et al. 2019). Cuba receives larvae from numerous upstream sources, and spawning bonefish in Cuba provide larvae for both local and distant (e.g., Bahamas) recruitment. Thus, activities that impact Cuban bonefish spawning processes have both local and regional implications.

Recreational fisheries contribute significantly to Cuban economies and societies through tourism activities (Figueredo et al., 2010). Current unsustainable fishing practices at spawning migrations and aggregations could negatively impact the Cuban economy and societies that rely on this species for food security, livelihoods, and economic benefits (Angulo-Valdes et al., 2017). The flats fishery also presents opportunities for alternative livelihoods including fishing guides, divemasters, cooks, and mechanics (Russell et al., 2012). An example of a fisher-to-tourism conversion exists in JDR, where a small floating hotel in the MPA caters to C&R fly-fishing (Pina-Amargos, 2008). Many hotel employees were fishers displaced by the creation of the MPA, but now work in hospitality, transportation, logistics, or as fishing guides within JDR (Pina-Amargos, 2008, Russell et al., 2012). Tourism assists the government in fisheries enforcement and further supports research by providing the logistical support for long-term continuous monitoring in JDR. Such activities help conserve marine resources upon which tourism depends, and staff conservation ethos is concomitantly high (Pina-Amargos et al., 2021).

Data limitations for bonefish in Cuba warrants the use of public participation and precautionary approaches for managing aggregation sites (Sadovy de Mitcheson, 2016). Few spawning-related locations (migrations and PSAs) have been scientifically identified in Cuba (Angulo-Valdes et al., 2017). One suggestion was for research to be carried out to determine the temporal characteristics of spawning seasons and locations for bonefish spawning aggregation and migration sites (Angulo-Valdes et al., 2017). LEK of fishers and fishing guides could aid in determining spawning migrations and aggregations, where MPAs can provide additional temporal and spatial zoning/protection for critical habitats utilized during spawning (Gerhartz-Muro et al., 2018). Thus, to replenish declining bonefish populations, a logistically feasible and economically practical management approach would focus on spawning aggregation identification and management, as this could provide a multitude of positive conservation outcomes in Cuba (Russell et al., 2012).

3.0 WHAT COULD EFFECTIVE BONEFISH MANAGEMENT LOOK LIKE IN CUBA?

The main source of data in this study comes from surveying and interviewing those working in the fishery or studying or managing bonefish in Cuba or the wider Caribbean. Cuban fisheries scientists (n=6) who are familiar with bonefish fisheries each completed an online survey with 32 questions using *Opinio* (an online survey platform). Fisheries scientists surveys were structured in three sections: 1) FSA management in Cuba; 2) pragmatic regulatory and management actions for conserving FSAs and bonefish spawning sites; 3) bonefish-specific information (e.g., conservation status, research gaps, management needs) (Appendix A). Cuban flats fishing guides (n=16) completed semi-structured interviews of 31 questions to aid researchers in obtaining valuable LEK about bonefish in the four management zones (Appendix B). These interviews were structured in three sections: 1) foundational, to determine duration of guide experience, fishing locations, fishing methods; 2) LEK about bonefish and spawning; 3) management needs, threats, and research gaps about bonefish. Questions to Cuban scientists and fishing guides were first translated from English to Spanish, the answers were given in Spanish and translated to English for analysis.

Survey answers were placed into aggregate form, categorized, and used to develop a proposal for a bonefish spawning area management framework, which includes specific management recommendations. An expert elicitation process with six experts who specialize in bonefish, FSA, or Cuban fisheries research and management was conducted to determine the pragmatism of the management recommendations relative to: achievability, feasibility, and whether recommendations are representative of local contexts. Expert feedback was then incorporated in a final draft of management recommendations. The interview and expert elicitation processes underwent ethics approval by the Dalhousie University Marine Affairs Program Ethics Review Standing Committee with a file number: MAPERSC# 2021-04.

3.1 Fisheries Scientist Survey Results

Six fisheries scientists completed a survey with 32 questions to gauge the understanding of spawning-related research and management in Cuba, identify challenges, specify management needs for bonefish, and determine which management actions are most effective for conserving spawning areas. All but one scientist indicated that research was occurring to determine species' spawning aggregation sites, mainly for tarpon, bonefish, cubera and mutton snapper, goliath grouper, and other species of commercial importance. All scientists stated that interviews with fishermen and LEK holders was the main method for determining spawning aggregation sites, with additional underwater surveys, collection of leptocephalus larvae with light traps, visual census, and egg sampling conducted to confirm spawning locations. However, all respondents highlighted that very few studies focus on spawning aggregation identification, and commercially important species receive greater research attention. Scientists described important aspects to consider when designing management recommendations for spawning locations, which were grouped under four aspect types: governance, economic, social, and environmental (Table 2). Scientists also provided perspectives on the challenges related to these aspect types (Figure 4). Notably, these challenges were persistent and occurred across aspect types. For example, a lack of human and physical resources was noted as the major challenge, and one that impacts all aspect types. Specifically, scientists indicated that resources (e.g., research vessels, equipment, and technology) are limited and rarely allocated towards spawning-related research, especially for species with low commercial value, as FSAs are usually difficult to access. The second most discussed challenge was access to financial support and resources. Finally, bureaucracy and lack of science were noted as additional challenges (Figure 4 and Table 2).

When asked how fishing guides and community members can participate in science and management, all six scientists stated that those members play a vital role in management and science of bonefish. Specifically, fishing guides and communities can collaborate in research, scientific and

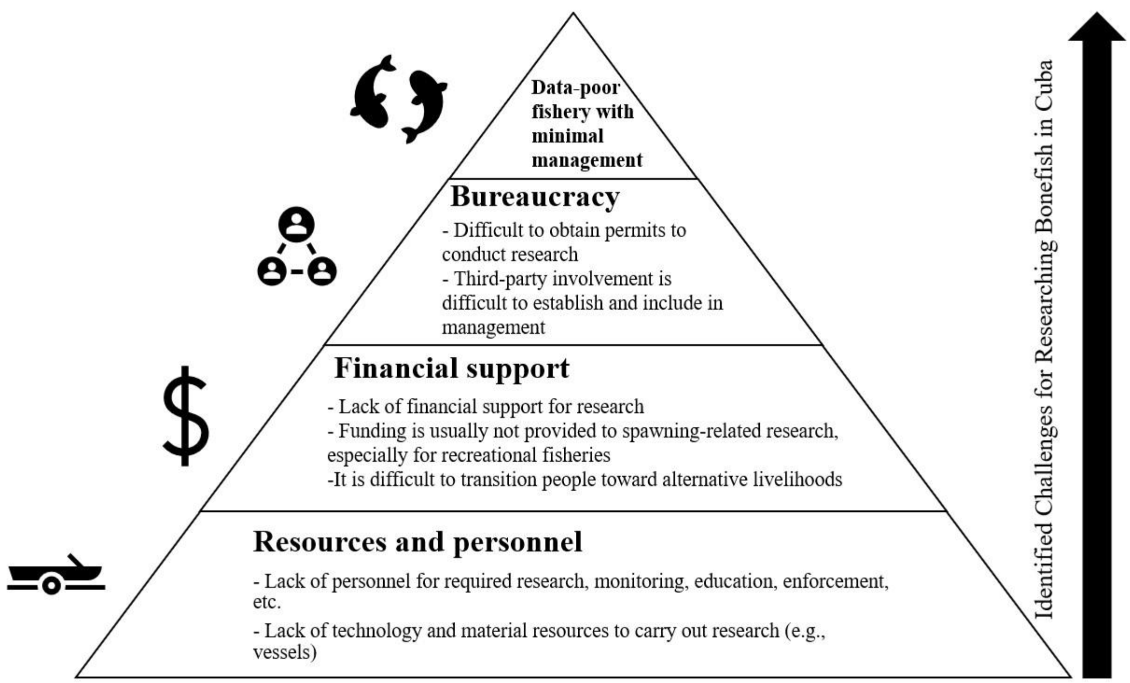

Figure 4: The main challenges of studying bonefish spawning events as identified by the surveyed scientists. The base of the pyramid exhibits the greatest challenge, with the level of challenge decreasing up the pyramid.

Table 2: Important aspects to consider when designing bonefish management strategies in the context of the identified challenges, as defined by scientists in surveys.

Aspects to consider when designing management recommendations	Sources
Governance - Need for scientific and compliance monitoring - Inter-sectoral participation is necessary - Integration of international examples - Enforcement presence - Evaluation of management measures	- Fisheries Scientist #03 - Fisheries Scientist #04
Economic - Types of fisheries - Development of economic alternatives (e.g., fisher incentives, alternative livelihood options, etc.) - Consideration of financial resources and funding for research	- Fisheries Scientist #01 - Fisheries Scientist #03 - Fisheries Scientist #04
Social - Relationship with local communities (e.g., the use of the species) - Where and when is the species most frequently caught - Inclusion and integration of fishermen, fishing guides and community members in management and education	- Fisheries Scientist #01 - Fisheries Scientist #03 - Fisheries Scientist #04
Environmental - Lifecycle of the species (e.g., physiological, reproduction, age of maturation, habitats utilized, migrations, etc.) - Precise spawning site identification - Habitats and species connectivity - Conservation status of species and its spawning sites - Knowledge of regional oceanography and larval transport - Threat category of species	- Fisheries Scientist #01 - Fisheries Scientist #02 - Fisheries Scientist #03 - Fisheries Scientist #04 - Fisheries Scientist #05 - Fisheries Scientist #06

compliance monitoring, education, and deterring illegal fishermen through surveillance and protection programs in conjunction with park rangers. Three scientists provided examples from Jardines de la Reina National Park, demonstrating how fishing guides are involved in research programs for different recreationally important species and act as deterrence mechanisms for illegal fishermen. A short-coming highlighted by three respondents was that inputs from coastal communities and fishing guides are rarely considered in management decision-making; however, inputs from these stakeholders can go through MPA specialists and/or researchers, who communicate management needs to their respective decision-makers. Respondents noted that anecdotal information from coastal communities can be used to identify aggregation sites, nursery habitats, and describe the status of different fisheries, and this information is regularly used as baselines for research projects by scientists.

When important habitats, like those that support FSAs are identified, all scientists stated that fisheries management and conservation strategies should be considered. Moreover, scientists specified that inter-institutional collaboration is crucial for making management viable. If spawning habitats are species-specific, additional information related to capture levels, status of fisheries, conservation status, ecological, and economic importance of that species are needed to initiate management actions. In many cases, scientists join fishers on their vessels to collect these aforementioned data, and train fishers to collaborate in research (e.g., genetic sampling of bonefish, tarpon, sharks, etc.). Once a solid scientific foundation for a species is reached, management actions are proposed in the form of written reports from scientists to decision-makers to initiate management actions and identify threats to vulnerable fish habitats or events.

To determine the most effective management strategies for conserving bonefish during reproduction, scientists were asked to rank six management options on a scale of 1-6 (1- the most effective and 6- least effective) (Table 3). Scientists identified spatial protections/zoning (μ=1.3) to be most effective, followed by community co-management (μ=2.2), temporal protections (μ=2.7), species-specific protections (μ=2.8), fishery input and output controls (μ=3.3), and minimum size limits (μ=4.0) for the management of bonefish spawning sites. However, all stated that a mixture of methods should complement each other, and a single management action will not suffice for species conservation. When asked to describe the possibilities for implementing precautionary and adaptive management when spawning sites are identified, scientists indicated that the recent 2020 Cuban Fisheries Law explicitly establishes that management of fishery resources are carried out under a precautionary approach. Furthermore, in Cuba, many MPAs have been established with specific objectives aimed at managing, conserving, and restoring marine ecosystems before anthropogenic, natural, or climate change impacts damage ecosystems. Scientists indicated that scientific reports do not always constitute protection as decision-makers may tailor management decisions based off experiences in other countries and are receptive to precautionary measures to ensure marine environments are conserved. However, an identified shortcoming was that precautionary management is stronger for species in critical condition, and less so with many other fish species that form aggregations.

When asked to gauge the extent of adaptive management applied to fisheries in Cuba, two scientists indicated low extent and four indicated moderate extent. Most respondents highlighted that management actions take many years to be implemented and management tools need to be modified according to research results, as management is not adaptive enough. For example, an important spawning aggregation within an MPA’s boundaries continues to be fished by the state fishery and measures should be implemented to focus efforts outside of the MPA and introduce appropriate zonation to conserve reproduction. A proposed strategy was to introduce a more inclusive research process to encourage third-party institutions to work alongside the Center of Fisheries Research (CIP - MINAL) to provide scientific support for management decision-making.

Table 3: Ranking of management measures for effectively conserving bonefish spawning areas in Cuba (1-more effective, 6-least effective). A colour scale from green to brown help depict which management measures were deemed to be the most effective by Cuban scientists.

Management Strategy	**Rank (mean)**
Spatial protection, including Marine Protected Areas (MPAs) that encompass spawning aggregations, migrations corridors, home ranges of species and critical habitats	1.3
Community-based fisheries management approaches, including educational marine areas, locally-managed marine areas, and involving fishing guides, fishers, youth and community members in education and monitoring programs.	2.2
Temporal/seasonal marine reserves that restrict fishing access to spawning aggregations and migration pathways for identified areas and species for a few months of the year.	2.7
Species-specific protections, including sale, export, or possession restrictions (seasonally or year-round).	2.8
Fishery input and output restrictions, including limited entry to a fishery, catch quotas, fish gear limitations	3.3
Minimum size limits to ensure growth, and maximum size limits to protect large, fecund females and large males	4.0

3.2 Fishing Guides

Sixteen professional fishing guides were interviewed in Spanish and asked to answer 31 questions by phone, each interview lasting between 30 and 40 minutes. Only one guide was from the Northwest management zone and otherwise, five guides from each of the other three management zones were interviewed (Figure 5). The longevity of experience as flats fishing guides ranged from 7 to 32 years (μ = 20 years, median = 21 years). Only two guides did not work between October to December; others worked year-round and indicated that the busiest seasons for flats fishing occurred from January to June. Guides highlighted that the top months for bonefish fishing based on abundance are January to March; catchability, November to March; and size, November to January; however, many indicated that size depends on locations and not months. When asked if guides notice an absence of bonefish during the year, April was selected by two guides based on the assumption that the species spawns during that month, and others discussed that absence is related to abrupt temperature changes, specifically, high water temperatures during summer months on the flats, and others stated there are no differences between months.

Guides were asked to describe changes in bonefish abundance, catchability, and size in their guiding grounds, which have been observed over the duration of their guiding career. Two guides (12%) described both decreases and increases in abundance based on hurricane and commercial fishing disturbances; seven (46%) noticed increases; four (24%) saw decreases; three (18%) indicated no

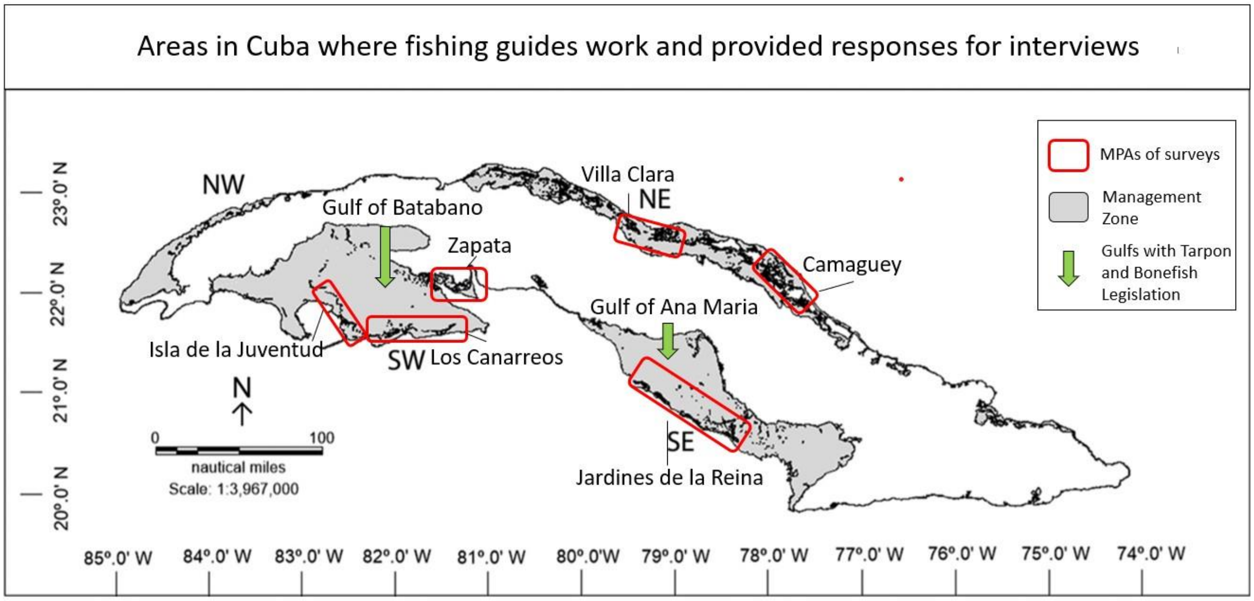

Figure 5: Map outlining the MPAs where guides who participated in interviews work and the two gulfs that have legislation in place to reduce harvest of bonefish and tarpon

differences. In addition, three (18%) guides stated that now bonefish are easier to catch; five (32%) noticed that bonefish are harder to catch; eight (50%) noticed no changes in catchability. Lastly, five (32%) guides indicated that bonefish are generally smaller in size in their guiding grounds; five (32%) noticed that fish are generally larger; six (36%) stated that fish size has remained the same. For those describing higher abundance, catchability, and larger sized fish, many attributed these beneficial aspects to the presence of management and status of fly-fishing activities being within protected area boundaries, in addition to patrolling by fisheries inspectors, and reporting of illegal fishing by fishing guides. Positive responses were received regularly from guides in JDR and Los Canarreos. These protected areas have been established with recreational fishing longer than other MPAs, which could have influenced how interview responses were provided. Moreover, this information can be considered for evaluation of MPA effectiveness in other areas. Fewer bonefish, smaller average sizes, and harder to catch fish were attributed to areas with illegal fishing, intense commercial fishing pressures, netting, overexploitation outside MPA boundaries, and lack of compliance monitoring. Catchability was also impacted from fly-fishing pressure (e.g., hooking and boat noise).

A description of a bonefish PSA was described to guides through the phone. All but one guide indicated familiarity with bonefish aggregations; however, responses varied, as some stated these congregations are feeding aggregations and others described spawning-related behaviours. Guides with experience working in multiple protected areas harbouring recreational fishing activities specified that aggregations are seen in Jardines de la Reina and Los Canarreos, but fewer to none in Isla de la Juventud and Villa Clara due to commercial and illegal fishing pressures. Responses for specific months of spawning were variable, and November to July is believed to be the spawning season for bonefish, as porpoising (a spawning behaviour of bonefish) and males releasing sperm are noticed when the species aggregates during these months.

In addition, all guides stated that they currently collect bonefish-related fisheries data (e.g., size of fish, area caught, number of fish caught per day), and all would like to be involved in spawning-related research and scientific monitoring, if programs are implemented. Guides also indicated interest in participating in compliance monitoring of spawning aggregation and migration sites. All guides stated that they are aware of vessels entering their guiding grounds to harvest finfish, specifically during snapper spawning seasons (April-July), as bonefish are harvested to be used as bait for these activities. Guides indicated that their presence deters illegal and commercial fishermen from entering their guiding grounds. When asked if management efforts are sufficient for sustaining bonefish populations, 14 guides indicated no, and 2 said yes. Comments and proposed solutions by guides are listed in Table 4.

3.3 Fishing Guide and Fisheries Scientists Importance Rankings of Bonefish Fisheries

Guides and scientists were asked to rank the commercial and recreational bonefish fisheries based on their importance for the people and economy of Cuba (Figure 6), with an additional question about the

Table 4: Interview results from fishing guides' LEK, indicating general comments and proposed management enhancement strategies for conserving bonefish.

Comments	Proposed solutions
Patrolling is strong in MPAs where fly fishing or diving takes place	Expand fly-fishing ports and educate stakeholders about bonefish ecological and economic importance
Management in Jardines de la Reina and Canarreos is sufficient and similar strategies should be implemented elsewhere.	Strengthen protections during reproduction and different life-history stages of flats fish (bonefish, permit, tarpon)
Bonefish keep the ocean floor full of life and clean. In areas where bonefish have been overfished, biodiversity has decreased	Generate fisheries management strategies, such as larger mesh size for nets
Fisheries inspectors are not permanently stationed in protected areas	Increase presence of fisheries inspectors to deter illegal fishers
Coordination between stakeholders needs to increase	Increase education and involve multiple stakeholders, such as commercial fishers, fly fishers and guides, and law enforcement.
Research should investigate bonefish life history stages	Focus research on bonefish movement patterns, spawning, nursery habitats, age and growth, and the ecological and economic importance of the species

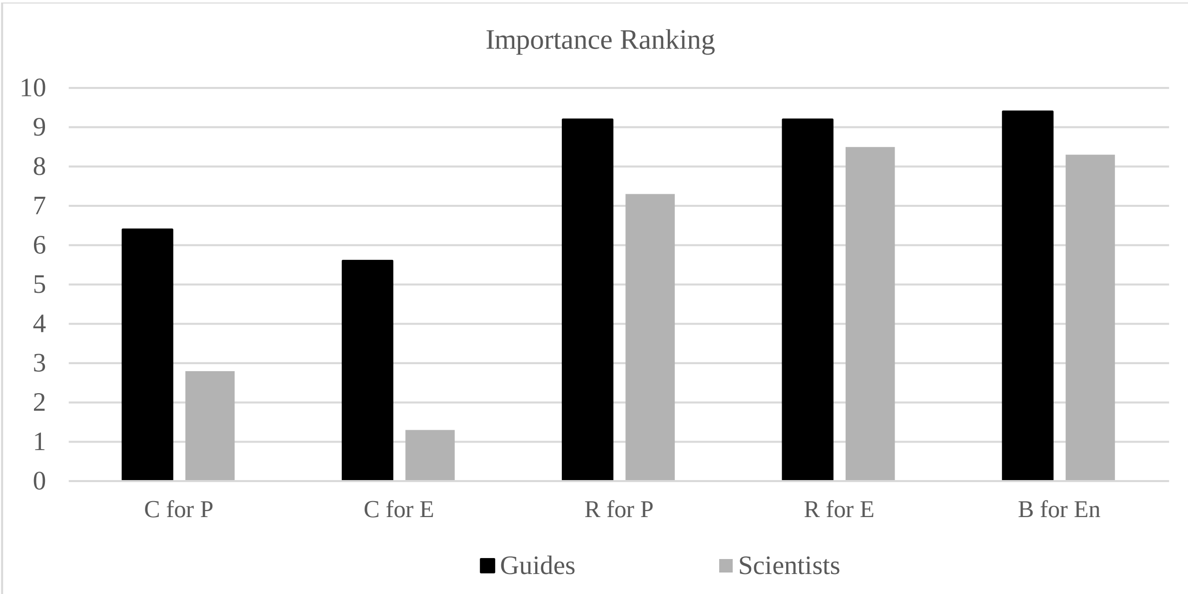

Figure 6: Displaying the importance ranking from scientists and fishing guides of bonefish. C: representing the commercial bonefish fishery; R: recreational bonefish fishery; P: for the people of Cuba; E: economy of Cuba; B for En: bonefish for Cuban ecosystems.

importance of bonefish for ecosystems within the jurisdiction of Cuba (1 = not important, 10 = incredibly important). The mean ranking for the recreational fishery and importance of bonefish for ecosystems was greater than the commercial fishery, especially when ranked by scientists. Fishing guides provided comments about the environmental importance of bonefish, stating that bonefish keep the ocean floor clean and alive. One fishing guide stated, "where bonefish have been overfished, the seafloor is covered by mazamorra, and these areas have less fish and biodiversity in general, as cassiopea, and other crustaceans are overly abundant where fewer bonefish thrive" (fishing guide #12). In addition, fishing guide #04 stated, "bonefish keep the bottom clean. Their feeding behaviour keeps the ocean floor full of life, and where there are fewer bonefish, those ocean bottoms have fewer fish and life in general". Eight fishing guides also highlighted this notion.

3.4 Management Recommendation Refinement

Drawing on the results of surveys (scientists/fisheries professionals) and interviews (guides), five additional experts with previous experience with recreational fisheries science or management in Cuba were interviewed as part of an expert elicitation process to evaluate the achievability and feasibility of each recommendation, and to assess the relevance of each for the Cuban context (Table 5). Experts provided feedback on each recommendation, with general comments discussing the challenges of each recommendation and additional aspects to consider. Where experts stated that management recommendations were feasible but not achievable, the main concerns were related to the implementation of measures (mainly management and regulatory changes), as these may be rejected or take many years to implement. For those that stated that recommendations were achievable, but not feasible, experts generally felt that poor monitoring, enforcement, and adaptive management may hinder the recommendations success. For example, in relation to expanding the fishery to areas outside of where flats fishing now occurs, one expert stated, "the broader application will be very challenging. In part because I think that the current concessions that are the flats fishery have somewhat invested interest in maintaining that control. So having fishing occur elsewhere out of their control might not be supported … Enforcement where they do fish is typically pretty good. Enforcement in other national parks is typically very poor, so I don't know about the feasibility with the expansion of that" (Expert #01).

For each recommendation, experts provided a set of challenges that relate to more than one recommendation. A summary table with the categorized challenges is presented in Table 6. Alongside identified challenges, experts provided additional comments to consider when finalizing management recommendations. Expert #02 stated "if management is to begin in Cuba for bonefish, economic information must be shared to MINAL. First, MINTUR must share economic information related to tourism, and MINAL must share the stock status of bonefish. A mechanism for this communication exists, which is the National Fisheries Commission, but MINAL has not received information that bonefish are worth more alive, than dead. This needs to happen". Expert #03 stated that "local communities need to see the benefits of recreational vs commercial fishing of this species, or else they will not comply to management measures". Stakeholder outreach, collaboration, and education were mentioned by many of the experts for researching, conserving, and further developing the flats fishery, and it is important for these processes to begin with the support from MINAL and MINTUR.

Table 5: Experts were asked to assess if each recommendation is achievable, feasible, and representative of Cuban context to evaluate the pragmatism of each strategy. Empty cells indicate that logistical requirements for performing a recommendation may not be feasible or achievable, or additional measures must be considered. Any cell with a "*" indicates that the expert was unsure and asked to seek further guidance from Cuban experts.

Recommendations	**Achievability**					**Feasibility**					**Context**				
	E1	E2	E3	E4	E5	E1	E2	E3	E4	E5	E1	E2	E3	E4	E5
R1. LEK should be integrated into management and aid scientists in determining bonefish PSA and migration route sites	x	x	x	x	x	o	o	o	o	o	□	□	□	□	□
R2. During perceived spawning periods, scientists can monitor spawning behaviour, collect egg samples, and submit reports to incorporate PSA and migration routes within protected areas or no-take zones	x	x	x	x	x	o	o	o	o	o	□	□	□	□	□
R3. MPAs with recreational fishing should investigate spawning sites and involve fishing guides in data collection, surveillance, and monitoring, while C&R fishing will act as a financial mechanism to fund further research, contribute to economies, and provide alternative livelihoods for communities	x	x	x	x	x	o	o	o	o	o	□	□	□	□	□
R4. Expand flats fishing ports to new areas in the country to aid in bonefish conservation and management	x	x	*	x	x	—	o	*	o	—	□	□	□	□	□
R5. MINTUR and MINAL need to communicate with each other to share economic information about bonefish C&R fishing and commercial fishing and initiate legal protection and management mechanisms for bonefish	x	x	x	x	x	o	o	o	o	o	□	□	□	□	□
R6. Laws should be approved to reduce commercial capture of bonefish, and limit capture to personal consumption (using hook and line) and recreational fishing to avoid overexploitation	—	x	*	x	—	o	o	*	o	o	□	□	□	□	□
R7. Compliance and education programs should be developed and opportunities for alternative livelihoods determined for those displaced by MPA designation	x	x	x	x	x	o	o	o	o	o	□	□	□	□	□
R8. Alongside MINAL, third-party institution collaboration should be encouraged to aid in scientific and compliance monitoring of vulnerable flats fishing grounds and species	—	—	x	x	x	o	o	o	o	o	□	□	□	□	□
R9. Annual inputs and evaluation of research results, compliance monitoring, community feedback, and other information needs to be assessed to provide further recommendations for changes and measure effectiveness of management measures by all stakeholder groups	x	x	x	x	x	o	o	o	o	o	□	□	□	□	□

x-achievable, o-feasible, □-representative of Cuban context, — difficult to achieve or deem feasible

Table 6: Challenges identified by experts for the management recommendations presented through the expert elicitation process.

Recommendation	Challenges	Source
R1	**Governance and Social** - Integrating and supporting management to implement and integrate LEK into management - Fisheries authority needs to strengthen relationships with coastal communities - Public participation is extremely poor, as avenues do not exist for the public to share ideas, criticism, feedback, or concerns	- Expert 1 - Expert 2
R2	**Governance and Economic** - Difficult to acquire financial and resource support - Successfully designating new zones or protected areas	- Expert 1 - Expert 2 - Expert 5
R3	**Governance and Economic** - Receiving logistical support for scientists (e.g., boats and technology) - Convince management to implement spatial protection - Spatial protection measures may not be enough	- Expert 1 - Expert 2 - Expert 3 - Expert 4
R4	**Governance, Economic and Social** - Will be difficult to obtain logistical support - Locals who target bonefish or other species in potential areas will not accept newly established MPAs - Alternative livelihoods in guided fishing are difficult to transition into (for cultural, traditional, and bureaucratic reasons) - Financial support is difficult to obtain	- Expert 1 - Expert 2 - Expert 3 - Expert 5
R5	**Governance** - Managers may not focus on bonefish management, as other issues may be prioritized	- Expert 5
R6	**Governance, Social, and Economic** - Fishers may not report their catches or comply to regulations - Enforcement and monitoring will be difficult because of a lack of personnel and resources - Backlash from communities and difficulties with transitioning locals toward alternative livelihoods	- Expert 1 - Expert 3 - Expert 5
R7	**Social and Economic** - Difficult to obtain resources and finances - Fishermen may not comply or embrace alternative livelihood options	- Expert 2 - Expert 3
R8	**Governance and Economic** - Funding will be a challenge, especially with US funding in Cuba - Difficult to obtain research permits and logistical support - Very difficult and unclear application process for research collaboration and permits	- Expert 1 - Expert 2 - Expert 4 - Expert 5
R9	**Social** - Avenues do not exist for stakeholder input and communication with fisheries authorities	- Expert 2

4.0 DISCUSSION

The protection of vulnerable habitats, such as spawning sites and nursery habitats are vital to sustaining fisheries (Erisman et al., 2018; Pittman and Heyman, 2020). Thus, an economically practical and logistically feasible strategy for sustaining the bonefish fishery in Cuba is to focus on the management of spawning events, specifically, PSAs and spawning migrations (Sadovy de Mitcheson et al., 2012). In this study, fisheries scientists indicated that spatial protection measures would be most effective for conserving bonefish at spawning sites because spawning-related management will provide the highest benefit-to-cost ratio for fisheries and conservation outcomes (Erisman et al., 2015). However, they emphasized that additional, complementary management actions are also needed. Pragmatic management in part means working within the current government structure and processes, should bonefish PSA management be something to prioritize in Cuban fisheries management. This research therefore found that it is essential to include local guides, LEK, and the context of MPAs in bonefish management.

4.1 Spatial management for bonefish conservation

In Cuba, recreational bonefish fishing occurs within MPA boundaries, and the process of identifying and managing perceived spawning areas should begin within protected areas. Although bonefish spawn offshore (Lombardo et al., 2020), the PSAs are in near-shore environments (Adams et al., 2019), and allocating resources towards travelling, financing, and identifying these locations would be less exhaustive than FSAs of traditionally researched species, such as snappers and groupers (Claro et al., 2019). These species aggregate to spawn in deep water shelf drop-offs that are difficult to access, which is an impediment for FSA research in Cuba and other Caribbean states with limited financial resources (Claro and Lindeman, 2003). Thus, with the support of the tourism industry, scientists could join fishing guides on research expeditions and follow a PSA identification protocol (Adams et al., 2019) to collect egg samples, observe spawning behaviour, and confirm sites, which are regularly vulnerable to overfishing. Adaptive, precautionary, and data-limited management – all emphasized in the Cuban Fisheries Law (2020) – can aid in appropriately zoning sites, expanding MPA boundaries, or establishing new MPAs, which can produce positive conservation outcomes for the fishery (EDF, 2019; Russell et al., 2012).

Within MPAs, appropriate zonation of spawning events would aid in effective enforcement, compliance, and scientific monitoring. If PSAs and migration routes are designated as no-take zones within MPAs and seasonal no-take zones outside MPAs, efforts should be made to allocate resources around new and full moons for monitoring compliance at these sites, specifically during the spawning season. Zones should include preservation, conservation, tourism zones, fish spawning aggregation (no-take), seasonal closure, and buffer zones. A similar approach for conservation, enforcement and monitoring of compliance and ecosystem health is found in a Belizean MPA (Glovers Reef Atoll Marine Reserve, Belize) (Strindberg et al., 2016). This Marine Reserve prioritizes spawning sites for fishes, conservation zones, seasonal closures, and wilderness zones for regular scientific and compliance monitoring (Strindberg et al., 2016). If conservation efforts go beyond spawning-specific management and protection, many ecosystems and species will benefit from bonefish conservation. Bonefish are umbrella species and management can have broader positive ecosystem conservation implications (Adams et al., 2019). In addition, bonefish can provide leverage for situations that might not otherwise gain traction, such as the protection of their prey and predator species, and habitats (Adams et al., 2019).

MPA planning and establishment should require clearly defined spatially and temporally distinct monitoring programs, and, as important, mechanisms to fund such activities. Without scientific and compliance monitoring, the effectiveness of MPAs on fish diversity and biomass cannot be assessed, and the primary value of these areas would be lost. Tourism fishing can help fund science and enforcement, while financially contributing to local communities and national economies. It is imperative that carrying capacities for each MPA be evaluated in collaboration with scientists and local stakeholders to determine how many visitors are permitted annually for each MPA, which will limit harm to ecosystems (Hernandez-Fernandez et al., 2016).

Generally, Cuban MPAs that harbour ecotourism activities, such as SCUBA diving and fly-fishing, have healthier ecosystems than other MPAs and unprotected areas in Cuba (Pina-Amargós et al. 2021). The recreational fishery has a relatively low environmental impact, as it is catch-and-release with generally high post-release survival, which also supports sustainable economies associated with ecotourism (Adams et al., 2021; Danylchuk et al., 2007). For example, JDR and Los Canarreos are older MPAs supported by legislation that restricts fishing for bonefish and tarpon in nearby gulfs: The Gulf of Ana Maria and Gulf of Batabano (Figure 5). Guides in these MPAs have indicated that catchability, abundance, and size of bonefish have been positively impacted by tourism, monitoring, management, and enforcement. If other MPAs embrace conserving flats fish, the benefits to local communities, economies, and ecosystems could be vast. For example, in The Bahamas the recreational bonefish fishery has an annual economic value of US $169 million, and supports more than 7,800 jobs (Fedler, 2019), while the fisheries' per capita economic impact exceeds that of standard tourism (Fedler, 2010). It is estimated that Cuban bonefish fishing has a similar impact, and it is imperative that management focusses on conserving the species and other flats fish that support the fishery (Angulo-Valdes et al., 2017).

4.2 The role of LEK in bonefish management

It is vital for LEK holders to be involved in management, monitoring, education, and research of bonefish home-ranges and spawning sites (Johannes, 2000). Cuban fishing guides are eager to participate in spawning-related research for bonefish. This can aid scientists in allocating resources and personnel towards these projects and gaining vital knowledge for conservation and management of flats species. Such partnerships with guides and fishing communities are consistent with the intent of the Convention on Biological Diversity (Berkes, 2007). These partnerships can result in positive engagement in discussions, exchanging observations and views, reflecting on information, evaluating outcomes, and adapting management to successfully achieve multiple social, economic, and ecological objectives (Berkes, 2007).

Fishing guides provided valuable knowledge about bonefish in Cuba that should help guide research and management. For example, guide LEK suggests that the spawning season in Cuba (November – July) may last longer than previously reported (November – April) (Adams et al., 2019; Danylchuk et al., 2011). LEK suggests that some PSAs and migration routes are within MPAs, and collaboration between researchers and experienced fishers can help positively identify these sites. Additional data collection from guides and through scientific sampling will test these observations.

Although management should begin with protecting spawning sites, additional aspects to promote long-term social, financial, and ecological sustainability of the flats fishery should be considered. LEK suggests that ecosystems with fewer bonefish have less biodiversity and an overabundance of *Cassiopea* spp. and cyanobacteria. Comparative studies between locations with abundant bonefish (e.g., JDR or Los Canarreos) and areas where bonefish have been overfished (e.g., Isla de Juventud) could test these observations. Economic valuation studies appear to be in-progress and should provide leverage for supporting catch-and-release, versus commercial bonefish fisheries. The establishment of positions, such as fishing guides, would enhance surveillance on the water and limit illegal fishing. The SOS Pesca Project is another positive example of how diverse stakeholders participated and LEK was utilized in marine science and decision-making related to fisheries, conservation, and coastal livelihoods, which resulted in greater stakeholder buy-in for management reforms and development of alternative livelihoods (Gerhartz-Muro et al., 2018; Miller et al., 2018).

Collaboration with guides to conduct science will increase resources available for research. Since resources are generally lacking for conducting research on bonefish, personnel and resources involved in the tourism flats industry can aid in identification and monitoring of bonefish PSA sites and evaluating the effects of management on the fishery. Fishing guides can lead collaboration, data-collection, and surveillance, as these individuals tend to understand the connection between the health of the environment and quality of the fishery (Oh and Ditton, 2006), and are on the water every day. Guides advocate for habitat conservation, which benefits many fisheries (Cowx et al., 2010). Finally, financial contributions from tourism fishing can be reinvested into research and expansion of catch-and-release fishing ports, further promoting research, surveillance, and conservation for areas that lack logistical and financial support for these activities.

Complementary management measures are needed to manage aggregate-spawning fishes. (Russell et al., 2012). In neighboring states (The Bahamas, Belize, and Florida), the recreational economic importance of bonefish has led to the implementation of catch restrictions of the species, which are limited to catch-and-release only, or for personal consumption using hook and line (Adams, 2017). Indeed, the importance of bonefish to national economies has encouraged the Bahamian government to develop five protected areas, and expand one, which are specifically established for the protection of PSAs, migration routes, and home-ranges for bonefish (Adams et al., 2019; Boucek et al., 2019). If spawning-associated harvests of bonefish continue in Cuba, reductions in size (age) at maturity and maximum sizes may continue in the country (Rennert et al., 2019). Furthermore, this can result in lower abundances, smaller sized fish, and earlier maturation, which have been documented for *Albula glossodonta* in the Pacific (Filous et al., 2021; Filous et al., 2019; Johannes and Yeeting, 2001).

4.3 Collaboration and Partnerships

This study highlights that collaboration amongst researchers, government administrators, and other stakeholders is the key to achieving beneficial management outcomes. Specifically, data-sharing is vital for the implementation of management actions for flats fish. MINAL and the Ministry of Tourism (MINTUR) should communicate economic and catch-related data about bonefish to enable effective management. Once economic estimates from MINTUR are shared with MINAL, bonefish economic contributions to national and local economies can be recognized. MINTUR can develop marketing arrangements to further advertise the unique opportunities that exist for international travellers to fish for bonefish in Cuba. In addition, avenues for citizens to communicate with MINAL should be developed to evaluate management actions and raise concerns about fishery-related information. Information must flow both ways to and from stakeholders to promote compliance on the water. Alongside MINAL, third-party institutions should be encouraged to participate in research, which can aid in data-collection, funding, and sharing of results.

Fishers or those displaced by protected area designation may resist complying with MPA establishment, and it is important to evaluate additional strategies for conserving bonefish. Experts highlighted that spatial protections occurring on a finite temporal basis may help reduce issues with stakeholders. A temporal fishing effort restriction for gulf corvina (*Cynoscicon othonopterus*) in Mexico represented a viable, less restrictive alternative to MPA designation, which aided in FSA conservation (Erisman et al., 2020). Thus, outside of MPAs, temporal closures during spawning periods may support species conservation and minimize impacts to stakeholders who use these areas. However, it has been emphasized by fishing guides, scientists, and experts that MINAL must recognize that bonefish are worth more alive, than dead. This recognition can generate beneficial opportunities to transition stakeholders toward alternative livelihoods in the recreational flats fishing industry or develop nation-wide species-specific restrictions. Although this approach can greatly benefit conservation, the expanse of the fishery and effort that can be sustained must be evaluated for MPAs incorporating C&R fishing, similarly to how Hernandez-Fernandez et al. (2016) determined carrying capacities in JDR for SCUBA diving.

Bonefish in the Wider-Caribbean-Region are valuable to multiple countries and stakeholders whether for livelihoods, ecological functions, or recreational tourism (Fedler, 2010; Fedler, 2013; Fedler, 2014). This species provides considerable income in the region and uncontrolled exploitation of their PSAs threaten natural resources, both economically and biologically. Therefore, it is vital for several countries to work jointly to conserve and manage bonefish. The Fisheries Research Center (CIP-MINAL) provides most data that initiates management in Cuba; however, if additional government agencies and international partners collaborate in research, diverse perspectives could lead to beneficial ecosystem sustainability outcomes. International partners could aid in providing resources and funding to support research and conservation, as fish that spawn in Cuba are important for other nations' fisheries (reproductive output from Cuba disperses to The Bahamas, Florida, Belize, Mexico, and Honduras) (Zeng et al., 2019). Collaboration between Cuba and other Caribbean states will benefit regional bonefish conservation. The importance of recreational fisheries should be discussed by the Caribbean Fishery Management Council (CFMC) and Western Central Atlantic Fishery Commission (WECAFC) to develop a working group for flats species. This approach has been taken for commercially important species like Nassau grouper and mutton snapper and should address other socio-economically and ecologically important species like bonefish (Sadovy de Mitcheson et al., 2018). It would be in the best interest for multiple nations that bonefish that spawn in Cuba are protected.

The following recommendations have been developed specifically for the management of bonefish in Cuba.

4.4 Recommendations

1. **Information exchange:** The National Fisheries Commission could be better operationalized to support information exchange between MINAL and MINTUR with relation to commercial and C&R catch and economic contributions from bonefish. Given the transboundary nature of bonefish reproductive output, information exchange and management coherence with neighboring Caribbean States should also be prioritized.

2. **Utilize LEK**: LEK can help locate spawning sites and a PSA identification protocol for bonefish (Adams et al. 2019) should be followed to observe spawning behaviours, collect egg samples and confirm spawning locations. Similarly, fishing guides should participate in data collection, surveillance, and management.

3. **Collaboration and Partnerships**: A platform should be implemented where scientists, fishing guides, fishers, communities, and management agencies interact and collaborate to identify bonefish PSA sites and spawning migration routes. Management strategies implemented for bonefish PSAs and migration routes should be generated and evaluated by all stakeholders within this collaborative space.

4. **Temporal and spatial management**: Formulate a temporal and spatial management or closure structure for PSAs and migration corridors and submit management recommendations to the Directorate of Fishing Regulations.

5. **Use what is already in place**: These actions should first be prioritized for MPAs where recreational fishing occurs since some level of protection is already in place. Management options include spatial no-take zones, seasonal closures, gear restrictions. Similarly, recreational C&R fishing should be used as a tool to provide scientists with financial and logistical resources for bonefish research.

6. **Reduce commercial capture of bonefish**: New laws should be implemented to greatly reduce or halt commercial harvest of bonefish and limit harvest to personal consumption (using hook and line) to prevent overexploitation.

5.0 CONCLUSION

In Cuba, commercially important fish species have received greater management attention then recreationally important fishes. Recreational fisheries, like the flats fishery, contribute greatly to Caribbean national economies, and the management of flats species would benefit financial, social, and ecological sustainability in Cuba. Bonefish are intensively harvested at multiple PSAs and spawning migration corridors in Cuba, and management strategies for conserving reproduction could generate and maintain positive results for the nation.

Overfishing at spawning sites for species like bonefish can have negative far-reaching population-level implications for national and regional fisheries. Management of harvest for spawning aggregations is a logistically feasible and economically practical strategy for sustaining species, which has the highest benefit to cost ratio for fisheries and conservation outcomes (Russell et al., 2012). Furthermore, if bonefish are released rather than harvested, they can create income repeatedly and yearly for the long-term. New policy and management instruments for spawning aggregation conservation for bonefish and other flats fish in Cuba should be developed with close collaboration and involvement from many stakeholders. Stakeholders, particularly fishing guides, who are involved in the flats fishery can hold leading roles in scientific and compliance monitoring at spawning sites, while spatial protection measures can further reduce pressures on spawning bonefish. In addition, adaptive and precautionary management, highlighted in the Cuban Fisheries Law (2020) enables spatial and temporal protections to be set for spawning sites, which will help achieve fishery sustainability. It is important to link site-focused partners to actively manage a cooperatively monitor bonefish spawning sites. Further studies of bonefish are needed, as well as assessments of fishery management actions for spawning and non-spawning periods. In this study, spatial protections were indicated as the most effective for spawning site protection; however, additional management measures, such as temporal or permanent species-specific fishing bans would further aid in bonefish conservation.

Cuba is a determined nation that has taken many steps towards preserving natural resources for national and global benefits. Cubans are eager to develop sustainable activities to promote socio-economic and environmental well-being. Recreational flats fishing has a minimal environmental impact, which can be used to provide alternative livelihood options for communities in Cuba, support research, and contribute to local and national economies.

APPENDIX A: Fisheries Scientist Survey Questions

Part 1: FSA and Cuban Fisheries Management

1. What institution do you work for? Within that institution, what department are you in?
2. What is the position you hold within your department?
3. Describe your professional responsibilities?
4. Could you please describe your area of expertise?
5. what type of research do you do and in what ways is your research applied (e.g., only do research that is applied to management)?
6. What species do you study?
7. Which management zone(s) do you work within? Select all that apply
8. Is research being conducted to determine species' spawning aggregation sites?

Can you please specify

A) Species
B) Methods for identifying spawning sites
C) Region in Cuba

9. Are spawning aggregations regularly studied in Cuba (e.g., for site identification, to determine species abundance, develop management measures, etc.)?
10. Can you please explain the challenges associated to researching spawning aggregations in Cuba?
11. Are resources (e.g., vessels, personnel, gear, technology, etc.) available to monitor spawning aggregations?
12. Of the 4 management zones in Cuba, are there any that would benefit from increased management presence? Please select all that apply
13. Which management measures would you say are the most effective for conserving vulnerable fish populations in Cuba? Please rank these from 1-6 (1-most effective, 6-least effective).
14. To what extent is research used to inform adaptive management strategies in Cuba?
15. Can you describe how information gathered by communities is incorporated into the development of conservation and management measures?
16. In what ways does the identification of vulnerable or important habitats for fish inform management decision making in Cuba?
17. To what extent is the precautionary approach to managing marine resources applied in Cuba?
18. What are important aspects to consider when designing management recommendations that conserve spawning aggregation sites?
19. How would you describe the impact of your department's involvement in the decision-making process for managing finfish in Cuba?

Part 2: Bonefish Specific Questions

1. Are you aware of the flats fishery in Cuba, which consists of three recreationally sought-after species: bonefish, tarpon, and permit?
2. If so, are bonefish, permit, or tarpon considered in management decision-making or research?
3. Is bonefish conservation or recreational fisheries management discussed in management meetings?

4. Which management measures would realistically be the most effective for conserving spawning bonefish in Cuba? Please rank these from 1-6 (1-most effective, 6-least effective).
5. Of the 4 management zones in Cuba, are there any that would benefit from increased management presence for bonefish? Please select all that apply
6. How important would you consider the commercial bonefish fishery for the people of Cuba? (1 – not important, 10 – incredibly important)
7. How important would you consider the commercial bonefish fishery for the Cuban economy? (1 – not important, 10 – incredibly important)
8. How important would you consider the recreational bonefish fishery for the people of Cuba? (1 – not important, 10 – incredibly important)
9. How important would you consider the recreational bonefish fishery for the Cuban economy? (1 – not important, 10 – incredibly important)
10. How important would you consider bonefish to be for marine environments within the jurisdiction of Cuba? (1 – not important, 10 – incredibly important)
11. to what extent can fishing guides or community members participate in science or co-management of bonefish?
12. What are the top management needs for bonefish management?
13. Is there anything else you would like to suggest to the researcher regarding this project? If so, please explain below

APPENDIX B: Fishing Guide Interview Questions

1. Which fisheries management zone do you guide within in Cuba (provide map for guidance)?
2. How many years of guiding experience do you have?
3. With clients, what are your guiding preferences for species to target? (top – 1, least – 3)
4. What are the typical angler preferences for species to target? (top – 1, least – 3)
5. What portion of the year do you work (select all that apply)?
6. What is the busiest season for you when guiding?
7. During the portion of the year when you are guiding anglers, what are the best months for fishing for bonefish (based on abundance)? Select all that apply.
8. During the portion of the year when you are guiding anglers, what are the best months for fishing for bonefish (based on catchability)? Select all that apply.
9. During the part of the year when you guide fishermen, what are the best months to catch bonefish (based on bonefish size)?
10. Do you notice an absence of bonefish during any of these months? Select all that apply
11. Have you noticed changes in bonefish size throughout the years of your guiding career? If you want to explain, please do.
12. Do you notice bonefish acting like they are migrating (moving in groups in one direction) during any particular months?
13. Have you noticed differences for the general trends in bonefish abundance near your guiding grounds?
14. Have you noticed changes in the catchability of bonefish over the years?
15. Have you ever encountered a large aggregation of bonefish? Please see Figure 1.

If so, what time of year did you see an aggregation of bonefish? Do you remember the month or perhaps the date? Please explain below.

In what type of habitat did you witness the aggregation of bonefish (e.g., depth, distance from shore, sandy substrate, hard rock substrate, marl substrate, etc.)? Please explain below.

What time of day did you witness an aggregation of bonefish? Please explain below.

16. Have you ever encountered commercial or unidentified vessels entering your guiding grounds and harvesting fish (if you have witnessed the harvesting of bonefish, please specify in the comment section)?
17. Are you aware of or have you heard about vessels entering guiding grounds to harvest finfish? Please explain below.
18. If you answered yes, could you please discuss (a) the time of year this occurs; (b) was this in the past, or does it still occur; (c) what years this happens(ed); (d) what species; (e) and location
19. If you have seen vessels harvesting species from an area in which you guide, does your presence deter harvesters from entering the area?
20. Do you collect information about the bonefish that are caught when you are guiding (e.g., size of fish, area caught, number of fish caught per day, etc.)?
21. If you do not collect bonefish-related information, would you like to be involved in such activities?

22. If a monitoring program were put in place to collect research about bonefish movements, identification of spawning aggregations, would you like to participate in such activities?
23. What would you like for this research to focus on, related to conserving the bonefish fishery?
24. How important would you consider the commercial bonefish fishery for the people of Cuba? (1 – not important, 10 – incredibly important)
25. How important would you consider the commercial bonefish fishery for the Cuban economy? (1 – not important, 10 – incredibly important)
26. How important would you consider the recreational bonefish fishery for the people of Cuba? (1 – not important, 10 – incredibly important)
27. How important would you consider the recreational bonefish fishery for the Cuban economy? (1 – not important, 10 – incredibly important)
28. How important would you consider bonefish to be for marine environments within the jurisdiction of Cuba? (1 – not important, 10 – incredibly important)
29. Do you think that management efforts for bonefish are sufficient for sustaining the population? If you would like to explain, please do.
30. Do you ever fish for bonefish for fun outside of your own management zone? If so, can you please specify which management zones you enter to fish for bonefish.
31. If there is additional information that you would consider important for consideration, can you please explain in the box below.

6.0 REFERENCES

Aburto-Oropeza, O., Erisman, B. E., Galland , G. R., Mascarenas-Osorio, I., Sala, E., & Ezcurra, E. (2011). Large recovery of fish biomass in a no-take marine reserve. *PLoS ONE*, 6(8), e23601. https://doi.org/10.1371/journal.pone.0023601.

Adams, A. J., Horodysky, A.Z., McBride, R.S, MacDonald, T.C, Shenker, J, Guindon, K., Harwell, H.D, Ward, R., Carpenter, K. (2013). Conservation status and research needs for tarpons (Megalopidae), ladyfishes (Elopidae), and bonefishes (Albulidae). *Fish* 15:280–311

Adams, A. J., Lewis, J. P., Kroetz, A. M., & Grubbs, D. R. (2021). Bonefish (Albula vulpes) home range to spawning site linkages support a marine protected area designation. *Aquatic Conservation: Marine Freshwater Ecosystems*, 31:1346–1353 https://doi.org/10.1002/aqc.3534.

Adams, A. J., Rehage, J. S., & Cooke, S. J. (2019). A multi-methods approach supports the effective management and conservation of coastal marine recreational flats fisheries. *Environmental Biology of Fishes*, 102: 105-115.

Adams, A. J., Shenker, J. M., Jud, Z. R., Lewis, J. P., Carey, E., & Danylchuk, A. J. (2019). Identifying pre-spawning aggregation sites for bonefish (Albula vulpes) in the Bahamas to inform habitat protection and species conservation. *Environmental Biology of Fishes*, 101(9) DOI 10.1007/s10641-018-0802-7.

Adams, A., Ajemian, M., Mejri, S., Wills, P., & Shenker, J. (2019). Bonefish spawning in the Bahamas – capturing the dynamics and behavior of a paramount recreational fishery species at a critical period in their life history. *Project Report*, 1-15.

Angulo-Valdes, J., & Hatcher, B. G. (2013). A New Methodology for Assessing the Effectiveness of Marine Protected Areas. *Rev. Invest. Mar*, 33(1) 55-70.

Angulo-Valdes, J., Navarro-Martinez, Z., Lopez-Castaneda, L., Frazer, T., & Adams, A. (2017). Collaborting on a New Vision for Cuba's Coastal Fisheries. *Bonefish and Tarpon Journal* , 40-44.

Angulo-Valdés, J.A. (2005). Effectiveness of a Cuban Marine Protected Area in Meeting Multiple Management Objectives (Doctoral dissertation). Retrieved from Dalhousie University's DalSpace Institutional Repository

Archer, S. K., Allgeier, J. E., & Semmens, B. X. (2014). Hot moments in spawning aggregations: implications for ecosystem-scale nutrient cycling. *Coral Reefs*, 34: 19-23.

Baisre, J. A. (2017). An overview of Cuban commercial marine fisheries: the last 80 years. *Bulletin Marine Science*, 94(2):359–375 https://doi.org/10.5343/bms.2017.1015.

Baisre, J. A. (2018). An Overview of Cuban Commercial Marine FIsheries: The last 80 years. *Bulletin of Marine Science*, 94: 359-375 https://doi.org/10.5343/bms.2017.1015.

Baisre, J.A. (2000). Chronicle of Cuban marine fisheries (1935–1995). Trend analysis and fisheries potential. FAO Fish. Tech. Paper 394. 26 p

Boucek, R. E., Lewis, J. P., Stwart, B. D., Jud, Z. R., Carey, E., & Adams, A. J. (2019). *Environmental Biology of Fishes*, 102:185–195 https://doi.org/10.1007/s10641-018-0827-y.

Bruger, G. E. (1974). Age, growth, food habits, and reproduction of bonefish, Albula vulpes, in south Florida waters. *Florida Department of Natural Resources, Marine Research Laboratory*.

Burke, L. & Maidens, J. (2004). Reefs at Risk in the Caribbean. Retrieved from http://www.wri.org/sites/default/files/pdf/reefs_caribbean_full.pdf

CBD/WG2020/2/3. (2020). Convention on Biological Diversity. Zero draft of the Post-2020 Global Biodiversity Framework.

Cicin-Sain, B., & Belfiore, S. (2005). Linking marine protected areas to integrated coastal and ocean management: A review of theory and practice. *Ocean and Coastal Management* , 48: 847-868.

Claro, R., & Lindeman , K. C. (2003). Spawning Aggregation Sites of Snapper and Grouper Species (Lutjanidae and Serranidae) on the Insular Shelf of Cuba . *Gulf and Caribbean Research*, 14 (2): 91-106.

Claro, R., Baisre, J. A., Lindeman, K. C., & Garcia-Arteaga, J. P. (2001). Cuban fisheries: historical trends and current status. *Claro R, Lindeman KC, Parenti LR, editors. Ecology of the marine fishes of Cuba*, Washington: Smithsonian Institution Press. p. 1–20.

Claro, R., Lindeman, K., Kough, A. S., & Paris, C. B. (2019). Biophysical connectivity of snapper spawning aggregations and marine protected area management alternatives in Cuba. *Fisheries Oceanography*, 28:33–42 DOI: 10.1111/fog.12384.

Claro, R., Sadovy de Mitcheson, Y., Lindeman, K. C., & Garcia-Cagide, A. R. (2009). Historical analysis of Cuban commercial fishing effort and the effects of management interventions on important reef fishes from 1960–2005. *Fisheries Research*, 99: 7-16 doi:10.1016/j.fishres.2009.04.004.

CNAP. (2013). Plan Del Sistema Nacional De Áreas Protegidas 2014-2020:. *Resumen Ejecutivo*, 304-307.

Consejo de Estado. (1996). Decreto - Ley No. 164 Reglamento de Pesca. Gaceta Oficial de la República de Cuba.

Cowx, I. G., Arlinghaus, R., & Cooke, S. J. (2010). Harmonizing recreational fisheries and conservation objectives for aquatic biodiversity in inland waters. *Journal of Fish Biology*, 76: 2194-2215.

Danlychuk, S. E., Danylchuk, A. J., Cooke, S. J., Goldberg, T. L., Koppelman, J., & Philipp, D. P. (2007). Effects of recreational angling on the post-release behavior and predation of bonefish (Albula vulpes): The role of equilibrium status at the time of release. *Journal of Experimental Marine Biology and Ecology* , 346: 127-133 doi:10.1016/j.jembe.2007.03.008.

Danylchuk, A. J., Cooke, S. J., Goldberg, T. L., Suski, C. D., Murchie, K. J., Danylchuk, S. E., . . . Phillip, D. P. (2011). Aggregations and oVshore movements as indicators of spawning activity of boneWsh (Albula vulpes) in The Bahamas. *Marine Biology*, 158:1981–1999 DOI 10.1007/s00227-011-1707-6.

Danylchuk, A. J., Lewis, J., Jud, Z., Shenker, J., & Adams, A. J. (2019). Behavioral observations of bonefish (Albula vulpes) during prespawning aggregations in the Bahamas: clues to identifying spawning sites that can drive broader conservation efforts. *Environmental Biology of Fishes*, https://doi.org/10.1007/s10641-018-0830-3.

EDF. (2019). Sustainability is on the Hook as Cuba Adopts New Fisheries Law, EDF Says. *Environmental Defense Fund*, https://www.edf.org/media/sustainability-hook-cuba-adopts-new-fisheries-law-edf-says.

Erisman , B. E., Gruss, A., Mascarenas-Osorio, I., Licon-Gonzalez, H., Johnson, A. F., & Lopez-Sagastegui, C. (2020). Balancing conservation and utilization in spawning aggregation fisheries: a trade-off analysis of an overexploited marine fish. *ICES Journal of Marine Science*, 77(1), 148–161. doi:10.1093/icesjms/fsz195.

Erisman, B. R., Aburto-Oropeza, O., Gonzalez-Abraham, C., Mascarenas-Osorio, I., Moreno-Baez, M., & Hastings, P. A. (2012). Spatio-temporal dynamics of a fish spawning aggregation and its fishery in the gulf of California. *Scientific Reports*, 2. doi:10.1038/srep00284.

Erisman, B., Heyman, W. D., Fulton, S., & Rowell, T. (2018). Fish spawning aggregations: a focal point of fisheries management and marine conservation in Mexico. *Gulf of California Marine Program, La Jolla, CA.*, 24p.

Erisman, B., Heyman, W., Kobara, S., Ezer, T., Pittman, S., Aburto-Oropeza, O., & Nemeth, R. (2015). Fish spawning aggregations: where well-placed management actions can yield big benefits for fisheries and conservation. *Fish and Fisheries,* DOI: 10.1111/faf.12132.

Ezer, T., Heyman, W. D., Houser, C., & Kjerive, B. (2011). Modelling and observations of high-frequency flow variability and internal waves at a Caribbean reef spawning aggregation site. *Ocean Dynamics*, 61, 581-598.

FAO. (2016). Recreational Fisheries Economic Impact Assessment Manual and Its Application in Two Study Cases in the Caribbean: Martinique and The Bahamas. *FAO Fisheries and Aquaculture Circular*, 1-107.

FAO. (2005). Code of conduct for responsible fisheries. Food and Agriculture Organization of the United Nations http://www.fao.org/3/v9878e/v9878e00.htm.

Fedler, A. (2010). The economic impact of flats fishing in the Bahamas. Report to the Boneifsh tarpon trust. Key Largo, Florida.

Fedler, A. (2013). Economic impact of the Florida keys flats fishery Report to Bonefish & Tarpon Trust. Key Largo, Florida.

Fedler, A. (2014). Economic impact of flats fishing in Belize. Report to Bonefish & Tarpon Trust. Key Largo, Florida.

Figueredo-Martin, T., Pina-Amargos, F., Angulo-Valdes, J., & Gomez-Fernandez, R. (2010). Pesca Recreativa en Jardines de la Reina, Cuba: Caracterizacion y Percepcion Sobre el Estado de Conservacion del Area. *Rev. Invest. Mar.* , 31(2):141-148.

Filous, A., Lennox, R. J., Beaury, J. P., Bagnis, H., Mchugh, M., Friedlander, A. M., . . . Danylchuk, A. J. (2021). Fisheries science and marine education catalyze the renaissance of traditional management (rahui) to improve an artisanal fishery in French Polynesia. *Marine Policy*, 104291 https://doi.org/10.1016/j.marpol.2020.104291.

Filous, A., Lennox, R. J., Eveson, P., Raveino, R., Clua, E. E., Cooke, S. J., & Danylchuk, A. J. (2019). Population dynamics of roundjaw bonefish Albula glossodonta at a remote coralline Atoll inform community-based management in an artisanal fishery. *Fisheries Management and Ecology*, 27: 200-214 DOI: 10.1111/fme.12399.

Garcia, E. (2014). Integrating Spatial Management with Fisheries Management. *Center for Coastal Studies Provincetown, Massachusetts, U.S.A. Workshop Report*, 5.

Gerhartz-Muro, J. L., Kritzer, J. P., Gerhartz-Abraham, A., Miller, V., Pina-Amargos, F., & Whittle, D. (2018). An evaluation of the framework for national marine environmental policies in Cuba. *Bulletin Marine Science* , 94(2): 443-459 https://doi.org/10.5343/bms.2017.1058.

Global Conservation. (2020). Jardines de la Reina National Park, Cuba. https://globalconservation.org/projects/jardines-de-la-reina-national-park-cuba/.

Gonzalez-Bernat, M. J., Fulton, S., Martinez, A. S., & Gonzalez, M. J. (2020). Policy Brief on Fish Spawning Aggregations. *MAR Fish Project*, *MAR FUND*, 24.

Gruss, A., Robinson, J., Heppell, S. S., Heppell, S. A., & Semmens, B. X. (2014). Conservation and fisheries effects of spawning aggregation marine protected areas: What we know, where we should go, and what we need to get there. *ICES Journal of Marine Science*, doi: 10.1093/icesjms/fsu038.

Hamilton, R. J., Giningele, M., Aswani, S., & Ecochard, J. L. (2012). Fishing in the dark-local knowledge, night spearfishing and spawning aggregations in the Western Solomon Islands. *Biological Conservation* , 145(1): 246-257 https://doi.org/10.1016/j.biocon.2011.11.020.

Hamilton, R. J., Potoku, T., & Montambault, J. R. (2011). Community-based conservation results in the recovery of reef fish spawning aggregations in the Coral Triangle. *Biological Conservation*, 144: 1850-1858 doi:10.1016/j.biocon.2011.03.024.

Hernandez-Fernandez, L., Olivera-Espinosa, Y., Figueredo-Martin, T., Gomez-Fernandez, R., Brizuela-Pardo L., Pina-Amargos, F. (2016). Incidencia del buceo autonomo y la capacidad de carga en sitios de buceo del Parque Nacional Jardines de la Reina. *Rev. Mar. Cost.*, *8*,9-27.

Heyman, W. D., Graham, R. T., Kjerfve, B., & Johannes, R. E. (2001). Whale sharks Rhincodon typus aggregate . *Marine Ecology Progress Series to feed on fish spawn in Belize.*, 215: 275-282.

Horta e Costa, B., Angulo-Valdes, J., Goncalves, J. M., & Barros, P. (2020). Assessing potential protection effects on commercial fish species in a Cuban MPA. *Aquaculture and Fisheries*, 5: 234-244 https://doi.org/10.1016/j.aaf.2020.04.001.

Hughes, A. T., Hamilton, R. J., Choat, J. H., & Rhodes, K. L. (2020). Declining grouper spawning aggregations in Western Province, Solomon Islands, signal the need for a modified management approach. *PLoS ONE* , 15(3): e0230485. https://doi.org/10.1371/journal.pone.0230485.

IPBES (2019): Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services

Johannes, R. E., & Yeeting, B. (2001). I-Kiribati Knowledge and Management of Tarawa's Lagoon Resources. *National Museum of Natural History Smithsonian Institute*, 1-24.

Johannes, R. E., Freeman, M. M., & Hamilton, R. J. (2000). Ignore fishers' knowledge and miss the boat. *Fish and Fisheries*, 1: 257-271.

Kritzer, J. P., & Liu, O. R. (2014). Fishery Management Strategies for Addressing Complex Spatial Structure in Marine Fish Stocks. *Environmental Defense Fund*, 29-57.

Lombardo, S. M., Adams, A. J., Danylchuk, A. J., Luck, C. A., & Ajemian, M. J. (2020). Novel deep-water spawning patterns of bonefsh (Albula vulpes), a shallow water fsh. *Marine Biology*, 167: 187 https://doi.org/10.1007/s00227-020-03799-3.

Miller, V., Mirabel-Patterson, A., Garcia-Rodriguez, E., Karr, K., & Whittle, D. (2018). The SOS Pesca Project: A Multinational and Intersectoral Collaboration for Sustainable Fisheries, Marine Conservation and Improved Quality of Life in Coastal Communities. *Lessons in International Cooperation*, 20(2): 65-70.

MINAL. (2015). National Plan of Action for the Conservation and Management of Chondrichthyes in the Republic of Cuba. *Ministry of the Food Industry*, Havana, Cuba. 48.

Morato, T., Hoyle, S. D., Allain, V., & Nicol, S. J. (2010). Seamounts are hotspots of pelagic biodiversity in the open ocean. *Proceedings of the National Academy of Science*, 107: 9707-9711.

Nemeth, R. S. (2005). Population characteristics of a recovering US Virgin Islands red hind spawning aggregation following protection. *Marine Ecology Progress Series*, 286: 81-97.

Nemeth, R. S., Wetherbee, B., & Shuvji, M. (2010). Interactions among three species of sharks and grouper spawning aggregations in the US Virgin Islands. *Proceedings of the Gulf and Caribbean Fisheries Institute*, San Juan, Puerto Rico, pp. 155–156.

Oh, C. O., & Ditton, R. B. (2006). Using recreation specialization to understand multi-attribute management preferences. *Leisure Sciences*, 28(4), 369– 384. https://doi.org/10.1080/01490400600745886.

Palomo, L., & Perez, A. U. (n.d.). 2019 Economic Impact of Flats Fishing in Quintana Roo, Mexico.

Perera-Valderrama, S., Hernandez-Avila, A., Ferro-Azcona, H., Cobian-Rojas, D., Gonzalez-Mendez, J., Caballero-Aragon, H., . . . Lara, A. (2020). Increasing marine ecosystems conservation linking marine protected areas and integrated coastal management in southern Cuba. *Ocean and Coastal Management*, 196: 105300 https://doi.org/10.1016/j.ocecoaman.2020.105300.

Perera-Valderrama, S., Hernandez-Avila, A., Gonzalez-Mendez, J., Moreno-Martinez, O., Cobian-Rojas, Ferro-Azcona, H., . . . Francisco-Rodriguez, L. F. (2018). Marine protected areas in Cuba. *Bulletin Marine Science*, 94(0):000-000 https://doi.org/10.5343/bms.2016.1129.

Pina-Amargos, F., Figueredo-Martin, T., & Rossi, N. A. (2021). The Ecology of Cuba's Jardines de la Reina: A review. *Revista Investigaciones Marinas*, 41: 2-42 http://www.cim.uh.cu/rim/.

Pina-Amargos, F., Gonzalez-Sanson, G., Cabrera-Paez, Y., & Cardodo-Gomez, P. E. (2008). Effects of Fishing Activity Reduction in Jardines de la Reina Marine Reserve, Cuba. *Proceedings of the 61st Gulf and Caribbean Fisheries Institute*, 352-357.

Pina Amargós F (2008) Efectividad de la Reserva Marina de Jardines de la Reina en la conservación de la ictiofauna. PhD dissertation. Universidad de la Habana, Centro de Investigaciones Marinas

Pina-Amargos, F., Gonzalez-Sanson, G., Jimenez del Castillo, A., Zayas-Fernandez, A., Martin-Blanco, F., & Red, A. (2010). An experiment of fish spillover from a marine reserve in Cuba. *Environmental Biology of Fishes*, 87: 363-372 DOI 10.1007/s10641-010-9612-2.

Pittman, S. J., & Heyman, W. D. (2020). Life below water: Fish spawning aggregations as bright spots for a sustainable ocean. *Conservation Letters*, 13:e12722 https://doi.org/10.1111/conl.12722.

Puga, R., Valle, S., Kritzer, J. P., Delgado, G., Estela de Leon, M., Gimenez, E., . . . Karr, K. A. (2018). Vulnerability of nearshore tropical finfish in Cuba: implications for scientific and management planning. *Bulletin Marine Science*, 94(2):377–392 https://doi.org/10.5343/bms.2016.1127.

Puritz, A. J. (2017). Evaluating Management Effectiveness of Marine Protected Areas in Cuba's Southern Archipelagos: A Comparative Analysis Between Punta Francés and Jardines de la Reina National Parks. *[University of Miami]*, https://scholarship.miami.edu/discovery/fulldisplay/alma991031447542502976/01UOML_INST:ResearchR.

Rennert, J. J., Shenker, J. M., Angulo-Valdes, J. A., & Adams, A. J. (2019). Age, growth, and age at maturity of bonefish (Albula species) among Cuban habitats. *Environmental Biology of Fishes*, 102: 253-265 https://doi.org/10.1007/s10641-018-0836-x.

Rhodes, K. L., & Warren-Rhodes, K. (2005). Management Options for Fish Spawning Aggregations of Tropical Reef Fishes: A Perspective . . *Report prepared for the Pacific Island Countries Coastal Marine*, TNC Pacific Island Countries Report No. 7/05.

Russell, M. W., Luckhurst, B. E., & Lindeman, K. C. (2012). Management of spawning aggregations. *Reef Fish Spawning Aggregations: Biology, Research and Management.*, (eds Y. Sadovy de Mitcheson and P.L. Colin). Springer, New York, pp. 371–404.

Russell, M. W., Sadovy de Mitcheson, Y., Erisman, B. E., Hamilton, R. J., Luckhurst, B. E., & Nemeth, R. S. (2014). *Status Report – World's Fish Aggregations 2014*, Science and Conservation of Fish Aggregations, California USA. International Coral Reef Initiative.

Sadovy de Mitcheson, Y. S., Cornish, A., Domeier, M., Colin, P. L., Russell, M., & Lindeman, K. C. (2008). A global baseline for spawning aggregations of reef fishes. *Conservation Biology*, 22(5), 1233– 1244. https://doi.org/10.1111/j.1523-1739.2008.01020.x.

Sadovy de Mitcheson, Y., & Domeier, M. (2005). Are aggregation fisheries sustainable: reef fish fisheries as a case study. *Coral Reefs*, 24: 254-262.

Sadovy de Mitcheson, Y., & Eklund, A. M. (1999). *Synopsis of biological data on the Nassau grouper, Epinephelus striatus (Bloch, 1792), and the jewfish, E. itajara (Lichtenstein, 1822). NOAA Technical Report NMFS No. 146*, NOAA/National Marine Fisheries Service, Seattle, WA, pp. 65.

Sadovy de Mitcheson, Y., & Erisman, B. E. (2012). The social and economic importance of aggregating species and the biological implications of fishing on spawning aggregations. *Reef Fish Spawning Aggregations: Biology, Research and Management.*, (eds Y. Sadovy de Mitcheson and P.L. Colin). Springer, New York, pp. 225–284.

Sadovy de Mitcheson, Y., Craig, M. T., & Bertoncini, A. A. (2013). Fishing groupers towards extinction: a global assessment of threats and extinction risks in a billion dollar fishery. . *Fish and Fisheries*, 14: 119-136.

Santella, C. (2019). Collaborative research efforts continue between BTT and University of Havana. *Bonefish and Tarpon Journal*, 38-41.

Snodgrass, D., Crabtree, R. E., & Serafy, J. E. (2008). Abundance, Growth, and Diet of Young-of-the-year Bonefish (Albula spp.) off the Florida Keys, U.S.A. *Bulletin of Marine Science*, 82(2): 185–193.

Strindberg, S., Coleman, R. A., Burns-Perez, V. R., Campbell, C. L., Majil, I., & Gibson, J. (2016). In-water assessments of sea turtles at Glover's Reef Atoll, Belize. *Endangered Species Research*, 31: 211-225 doi: 10.3354/esr00765.

Tobin, A., Currey, L., & Simpfendorfer, C. (2013). Informing the vulnerability of species to spawning aggregation fishing using commercial catch data. *Fisheries Research* , 143, 47-56.

UN Atlas of the Oceans. (2016). Types of Fisheries. http://www.oceansatlas.org/subtopic/en/c/1303/.

Wingfield, D. W., Peckham, H. S., Foley, D. G., Palacios, D. M., Lavaniegos, B. E., Durazo, R., . . . Bograd, S. J. (2011). The Making of a Productivity Hotspot in the Coastal Ocean. *PLoS one*, 6(11): e27874 doi:10.1371/journal.pone.0027874.

Zeng, X., Adams, A., Roffer, M., & He, R. (2019). Potential connectivity among spatially distinct management zones for Bonefish (Albula vulpes) via larval dispersal. *Environmental Biology of Fishes*, 102: 233-252 https://doi.org/10.1007/s10641-018-0826-z.