

# A stakeholder-engaged approach to evaluating spawning aggregation management as a strategy for conserving bonefish (*Albula vulpes*) in Cuba

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**Abstract** Animals that congregate in large numbers to reproduce in spatially and temporally distinct locations are particularly susceptible to overexploitation. Many fishes form spawning aggregations that are intentionally targeted given ease of capture. 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, we use Cuba as a case study to inform the development and refinement of management strategies 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

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Florida Atlantic University Harbor Branch Oceanographic Institute, 5600 US 1, Fort Pierce, FL 33946, USA 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.

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#### Introduction

Marine environments are threatened by anthropogenic disturbances (Sobel and Dahlgren 2004). For fisheries, recurring management failures and declines of fish populations have prompted societies to demand alternative management actions in many regions of the world (Field et al. 2002; Angulo-Valdés 2005). Effective management and conservation are required to ensure fisheries and their associated economies are sustainable (Caddy 1999; Hughes et al. 2020). Of particular importance in the Caribbean Sea are economically important recreational fisheries (FAO 2016). One of the most economically valuable recreational fisheries is the flats fishery, which is mostly catchand-release (C&R), comprised four target species: tarpon (Megalops atlanticus), permit (Trachinotus falcatus), common snook (Centropomus undecimalis) and bonefish (Albula vulpes) (Figueredo-Martín et al. 2010; Adams 2017).

The flats fishery has an estimated annual economic impact of US\$465 million in the Florida Keys 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 (Figueredo-Martín et al. 2010). The economic value of the flats fishery should provide leverage for developing sustainable management measures to safeguard critical fish habitats and life-cycle events, such as fish spawning aggregations (FSAs) (Erisman et al. 2017; Adams et al. 2021).

FSAs are large gatherings of conspecific fish that meet predictably and repeatedly for the purpose of reproduction (Domeier 2012; 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. 2017). However, FSAs are often overexploited because fishers can harvest the largest number of fish with the least amount of effort (Gonzalez-Bernat et al. 2020), which may lead to population-level collapse (Sadovy de Mitcheson and Erisman 2012). For example, in Mexico, fishers harvest more than two million individuals (5000 t) of gulf corvina (*Cynoscion othonopterus*) in < 30 days at a single FSA site (Erisman et al. 2017). 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. 2017). Closures of specific geographic locations to fishing seasonally or permanently (e.g., marine protected areas; MPAs) 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., red hind recovery in the US Virgin Islands, Nemeth 2005). Moreover, enforcement can be relatively effective for FSAs because they 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, such as bonefish and other flats fishery species (Russell et al. 2012). Additional management measures include species-specific protections (export, sale, or possession of species is restricted) and fisheries input and output controls (catch quotas, limited entry to a fishery or gear restrictions) (Grafton et al. 2010).

Twelve species of bonefish have been identified worldwide (Pickett et al. 2020), of which four species occur in the Caribbean. *Albula vulpes* supports the flats fishery in the Caribbean and is listed as Near Threatened on the IUCN Red List, due to habitat loss and fragmentation, coastal development, declines in water quality and fishing mortality arising from commercial, artisanal and recreational sectors (Adams et al. 2013). 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 trophic dynamics, by influencing crustacean and smaller fish populations and being prey for predators (e.g., sharks and barracudas) (Adams et al. 2019; Boucek et al. 2019; Snodgrass et al. 2008; Bruger 1974). This species is especially vulnerable during their reproductive phase because they form large aggregations (>5000 individuals) in spatially and temporally distinct locations (Danylchuk et al. 2011, 2019; Adams et al. 2019), so are susceptible to overexploitation and habitat loss. Primarily near full and new moons between October and April (identified spawning season in the Bahamas), bonefish migrate from their home ranges (<2 m depth) to shallow protected bays (5-10 m depth) near deep water, where they form pre-spawning aggregations (PSAs) that may last 1 to 5 days (Danylchuk et al. 2011; Adams et al. 2019). Bonefish move offshore at dusk where they have been documented descending > 137 m 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 if overexploited or habitats are degraded or destroyed (Erisman et al. 2017; Pittman and Heyman 2020).

Recent estimates of larval transport for bonefish from known and suspected spawning locations in the Caribbean Sea suggest that Cuba may play a central role in regional population connectivity (Zeng et al. 2019). Presumably, Cuba receives larvae from local and numerous upstream sources, and spawning bonefish in Cuba provide larvae for both local and distant recruitment (e.g., The Bahamas, Florida, Belize, Mexico, Honduras) (Zeng et al. 2019). Thus, activities that impact Cuban bonefish spawning processes have both local and regional implications. However, bonefish populations in Cuba are declining from overfishing at spawning sites (Angulo-Valdés 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-Valdés et al. 2017). Harvested bonefish are then used as bait for long lines, sold in black and legal markets, incorporated into animal feed or used for personal consumption (Borroto 2011; NPOA-Sharks 2015; Santella 2019). The pressures on bonefish PSAs in Cuba are substantial which may trigger bonefish to spawn at earlier ages/smaller sizes (Beets 2000; Rennert et al. 2019), thus minimizing their reproductive potential (Filous et al. 2021). Additional research is needed to quantify aggregation-fishing impacts on bonefish to inform the implementation of fisheries management strategies that protect bonefish reproduction (Angulo-Valdés et al. 2017).

Data limitations for bonefish in Cuba warrant the use of public participation and adaptive and precautionary approaches for managing aggregation sites (Sadovy de Mitcheson et al. 2008). Few spawningrelated locations (migrations and PSAs) have been scientifically identified in the country (Angulo-Valdés et al. 2017), and it is vital to gather local ecological knowledge (LEK) to integrate that information into research and management of bonefish (Johannes et al. 2000). Thus, the objective of this research is to develop management strategies for bonefish spawning aggregations in Cuba and thereby provide recommendations based on international best practices and experiences that are feasible, achievable and respectful of local context. To do so, we completed surveys with Cuban fisheries professionals and interviewed Cuban fishing guides. Then, we refined management recommendations with an additional interview process with fisheries professionals to develop six recommendations for the conservation of bonefish spawning sites in Cuba.

#### Methods

#### Study area

The study focused on 15 smaller MPAs in Cuba where fishing guides operate, which occur in six larger recreational fishing zones: Jardines de la Reina (recreational fishing (RecFish) established in 1996), Isla de la Juventud (RecFish-2005), Canarreos (RecFish-2008), Camaguey (RecFish-2012), Villa Clara (RecFish-2014) and Cienaga de Zapata (RecFish-2016) (Fig. 1). The MPAs have recreational fishing occurring within their boundaries and may be designated as National Parks, Resource Management Protected Areas, Faunal Refuges, and Natural Outstanding Landscapes. The remainder of the paper will refer to the six aforementioned zones and not specific MPAs within those zones to reduce the chance for guides to be identified. These MPAs are managed by the National Enterprise for the Protection of Flora and Fauna (ENPFF), The Ministry of the Food Industry



Fig. 1 Map outlining the MPAs where guides who participated in interviews work. Areas with restrictions to bonefish and tarpon harvest are marked with green arrows, and grey

(MINAL), Gaviota (a Cuban tourism operator), or the Cuban Board of Administrators (BA).

Fisheries in Cuba are managed and controlled by The Ministry of the Food Industry (MINAL) under a centralized system, and additional rulemaking and research involve the Directorate of Fisheries areas indicate the four Cuban fisheries management zones: Northwest (NW); Northeast (NE); Southwest (SW); Southeast (SE) (Permission provided by Puga et al. 2018)

Regulations, Fisheries Research Center (CIP) and the National Fisheries Commission (Fig. 2) (Puga et al. 2018). The marine area is divided into four fisheries management zones (Fig. 1). Approximately 25% (ca. 17,444,390 ha) of this area is spatially protected as MPAs (Puga et al. 2018). MPAs in Cuba range from



Fig. 2 Cuban fisheries management and governance structure

open access to limited harvest. The majority of MPAs are open access with poor enforcement; however, other MPAs allow for the harvest of highly regulated spiny lobster, C&R recreational fishing and SCUBA diving (Angulo-Valdés et al. 2017).

## Surveys, interviews and analysis

Cuban fisheries professionals (n=6) who are involved in recreational flats fishery research in Cuba were identified and recruited for this research, all of whom are scientists. These individuals are familiar with bonefish fisheries, and each completed an online survey with 32 questions using Opinio (an online survey platform), with open ended, selection and ranking questions (Online Resource 1). These surveys were structured in three sections as follows: (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). Since there are few fisheries professionals in Cuba that research and design management strategies for flats fishery species, this study had a relatively low sample size. Although the sample size was low, those who participated provided much information to uncover important needs for managing and sustaining bonefish in Cuba, and expert insight guided the development of realistic recommendations for this species. These data were also collected in the peak of the COVID-19 pandemic, which introduced difficulties with recruiting, interviewing and surveying bonefish experts (fisheries professionals and fishing guides) in Cuba. Overall, the experts interviewed as part of this project represented a significant portion of the total number of people knowledgeable of Cuban flats fisheries.

Cuban flats fishing guides (n=16) were recruited by one of the authors to provide insightful local ecological knowledge (LEK), which helped identify management needs and the statuses of bonefish fisheries in different areas of the country. These individuals, who were all male and identified guiding as their principal form of income, completed semi-structured interviews by phone and were asked 31 questions (Online Resource 1). These interviews were structured in three sections as follows: (1) foundational, to determine duration of guide experience, fishing locations, fishing methods; (2) perspectives on bonefish and spawning; (3) management needs, threats and research gaps about bonefish. Questions to Cuban professionals and fishing guides were first translated from English to Spanish; the answers were given in Spanish and translated to English for analysis.

Survey and interview answers were aggregated and categorized. Informative quotes were highlighted for inclusion in the manuscript; open-ended questions were grouped into themes and key takeaways helped to develop recommendations. Themes were determined inductively based off commonalities in responses from participants, which helped the authors highlight management priorities for bonefish. Note that because the participant number was low, formal coding of data did not occur; rather authors derived themes directly from uncoded material. Multiple choice results are presented as percentages, while questions that asked for rankings were calculated and are shown as averages. The authors used the results to develop a proposal for a bonefish spawning area management framework, which includes specific management recommendations.

An interview process with experts - three additional fisheries professionals and two of the previously interviewed Cuban fisheries professionals 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 respectful of local contexts. These experts were recruited based on their knowledge of FSA and/or bonefish management in the Caribbean. Each participant underwent an elicitation process to determine if potential management recommendations developed by the authors could be altered to accommodate regional fisheries management practices/strategies. It was necessary to re-sample some of the Cuban fisheries professionals to determine if the potential management recommendations would be appropriate for the Cuban context of fisheries research and management. Since these experts are familiar with the status of recreational fisheries management and how bonefish can be included into national fisheries research and management, their involvement was invaluable for the finalization of recommendations. Biases may exist, as the re-sampled Cuban fisheries professionals also answered the previous survey that led to the development of management recommendations. Expert feedback was then incorporated in a final draft of management recommendations.

## Results

Fisheries professionals surveys

All professionals indicated that very few studies have occurred or are occurring to determine species' spawning aggregation sites in Cuba. The studies that are available focus on commercially important species, such as cubera (Lutianus cyanopterus) and mutton (Lutjanus analis) snappers, and goliath grouper (Epinephelus itajara). Recently, tarpon and bonefish have gained traction in fisheries research. All professionals stated that interviews with fishers and other LEK holders was the main method for determining spawning aggregation sites, with additional underwater surveys, visual census and egg sampling conducted to confirm spawning locations. Important aspects to consider when designing management recommendations for spawning locations were grouped under four aspect types as follows: governance,



Fig. 3 The main challenges of studying bonefish spawning events as identified by the surveyed fisheries professionals

economic, social and environmental (Table 1). Professionals also provided perspectives on the challenges related to these aspect types (Fig. 3). Notably, these challenges were persistent and universal. For

 Table 1
 Important aspects to consider when designing bonefish management strategies in the context of the identified challenges, as defined by fisheries professionals 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	<ul> <li>Fisheries professional #03</li> <li>Fisheries professional #04</li> </ul>
Economic -Types of fisheries -Development of economic alternatives (e.g., fisher incentives, alternative livelihood options etc.) -Consideration of financial resources and funding for research	<ul> <li>Fisheries professional #01</li> <li>Fisheries professional #03</li> <li>Fisheries professional #04</li> </ul>
<ul> <li>Social</li> <li>-Relationship with local communities (e.g., the use of the species)</li> <li>-Where and when is the species most frequently caught</li> <li>-Inclusion and integration of fishers, fishing guides and community members in management and education</li> </ul>	<ul> <li>Fisheries professional #01</li> <li>Fisheries professional #03</li> <li>Fisheries professional #04</li> </ul>
<ul> <li>Environmental</li> <li>-Lifecycle of the species (e.g., physiological, reproduction, age of maturation, habitats utilized, migrations etc.)</li> <li>-Precise spawning site identification</li> <li>-Habitats and species connectivity</li> <li>-Conservation status of species and its spawning sites</li> <li>-Knowledge of regional oceanography and larval transport</li> <li>-Threat category of species</li> </ul>	<ul> <li>Fisheries professional #01</li> <li>Fisheries professional #02</li> <li>Fisheries professional #03</li> <li>Fisheries professional #04</li> <li>Fisheries professional #05</li> <li>Fisheries professional #06</li> </ul>

example, a lack of human and physical resources was noted as the major challenge, and one that impacts all aspect types. Specifically, 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. Combined, these challenges resulted in limited capacity to address data needs. Finally, bureaucracy and lack of science were noted as additional challenges (Fig. 3 and Table 1).

When asked how fishing guides and community members can participate in science and management, all six professionals 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 compliance monitoring, education and deterring illegal fishing through surveillance and protection programs in conjunction with park rangers. Three professionals provided examples from Jardines de la Reina National Park (JDR), demonstrating how fishing guides are involved in research programs for different recreationally important species and act as deterrence mechanisms for illegal fishers. A shortcoming 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 then communicate this information to respective decision-makers. Respondents noted that anecdotal information from coastal communities can be used to provide guidance for identifying aggregation sites, nursery habitats and describe the status of different fisheries. This information is regularly used as baselines for research projects by scientists.

When important habitats, like those that support FSAs, are identified, all professionals stated that fisheries management and conservation strategies should be considered. Moreover, professionals specified that inter-institutional collaboration is crucial for making management viable. Professionals stated that 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 and sharks). They indicated that 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, professionals were asked to rank six management options on a scale of 1–6 (1 — the most effective and 6 — least effective) (Table 2). Professionals identified spatial protections/zoning (mean=1.3) to be most effective, followed by community co-management (mean=2.2), temporal protections (mean=2.7), species-specific protections (mean=2.8), fishery input and output controls (mean=3.3) and minimum size limits (mean=4.0) for the management of bonefish spawning sites. However, all stated that a mixture of complementary methods should be used, and a single management action will not suffice for species

Table 2 Ranking of management measures for effectively conserving bonefish spawning areas in Cuba (1 — more effective, 6 — least effective)

Management strategy	Rank (mean)
Spatial protection, including Marine Protected Areas (MPAs) that encompass spawning aggregations, migrations cor- ridors, 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

conservation. When asked to describe the possibilities for implementing precautionary and adaptive management when spawning sites are identified, professionals 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. Professionals indicated that decision-makers are receptive to data in scientific reports. If reports are unavailable, decision-makers may tailor management actions based on experiences in other countries and are receptive to precautionary measures to conserve marine areas if justification for protection exists in neighbouring countries. However, an identified shortcoming was that precautionary management is stronger for species in critical condition, and less so with many other fish species even if they are susceptible because they aggregate to spawn.

When asked to gauge the extent of adaptive management applied to fisheries in Cuba, two professionals 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 Environ Biol Fish

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 fishing 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 thirdparty institutions to work alongside the Center of Fisheries Research (CIP — MINAL) to provide scientific support for management decision-making.

# Fishing guide interviews

The longevity of experience as flats fishing guides ranged from 7 to 32 years (mean=20 years, median=21 years) (Table 3). Two guides did not work between October and December; all 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

**Table 3** Fishing guideresponses for changesin abundance, size, andcatchability of bonefish inthe six recreational fishingzones. Dates are the yearsthat the site was designatedas a Recreational FisheryZone

Location	Guide experi- ence	Abundance	Size	Catchability
Canarreos (2008)	7	1	↑	
	20	1	↑	$\uparrow$
Isla de la Juventud (2005)	13	Ļ	$\downarrow$	-
	30	$\downarrow$	$\downarrow$	-
Cienaga de Zapata (2016)	23	\$	$\downarrow$	$\downarrow$
	21	↑	$\downarrow$	$\downarrow$
Jardines de la Reina (1996)	32	-	-	-
	30	↑	<b>↑</b>	-
	21	Ļ	-	-
	18	Ļ	-	-
	18	-	-	$\downarrow$
Camaguey (2012)	30	-	-	-
	10	↑	-	-
	10	\$	$\downarrow$	$\downarrow$
Villa Clara (2014)	15	↑	↑	$\downarrow$
	21	1	↑	$\uparrow$

 $\uparrow$ : increasing,  $\downarrow$ : decreasing, -: no changes,  $\uparrow$ : decreased then increased

temperature changes — specifically, high water temperatures on the flats during summer months — and others stated no differences between months.

There were no clear trends when guides were asked to describe changes in bonefish abundance, catchability and size in their guiding grounds observed over the duration of their guiding career (Table 3). Here, catchability differs from the definition used for harvest fisheries (e.g., "the proportion of the fish stock removed per unit effort" Post et al. 2002) and is instead more similar to the concept of "trap bias" in mark-recapture experiments, where animals might be "trap happy" or "trap shy" (e.g., Reinhardt and Hrodey 2019). Here, we define catchability as the likelihood that fish and angler attempts to catch are caught. Fish in an unfished population are more likely to be "trap happy", and if presented with a lure by anglers are likely to hit the lure and be caught. In contrast, fish in a heavily fished population are more likely to be "trap shy", and not react to or actively avoid lures presented by anglers. 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 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 (Table 3). For those describing higher abundance, catchability and larger sized fish, many attributed these beneficial aspects to increased presence of management and status of fly-fishing activities being within MPAs, in addition to patrolling by fisheries inspectors, and fishing guides reporting illegal fishing. 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 flyfishing pressure (e.g., hooking and boat noise).

Bonefish PSAs and spawning behaviours were described to guides through the phone. All but one guide indicated familiarity with bonefish aggregations; however, responses varied, as some stated these 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 JDR and 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 and potentially year-round.

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 fishers from entering their guiding grounds. When asked if management efforts are sufficient for sustaining bonefish populations, 14 guides indicated no, and 2 said yes (those who answered "yes" operate in Jardines de la Reina and Canarreos, which are very popular tourism sites for diving and fly fishing in Cuba) (Table 4).

Fisheries professionals and fishing guide importance rankings of bonefish fisheries

Fisheries professionals and guides were asked to rank the commercial and recreational bonefish fisheries based on their importance for the people and economy of Cuba (Fig. 4), with an additional question about the 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 fisheries professionals. 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, 
 Table 4
 Interview results from fishing guides' LEK, indicating general comments and proposed management enhancement strategies for conserving bonefish

Comments	Proposed solutions
Patrolling is stronger in MPAs where fly fishing or diving takes place	Expand fly-fishing ports and educate stakeholders about bonefish ecological and economic importance
Greater management and surveillance efforts have benefitted flats species in Jardines de la Reina and Canarreos, 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



Fig. 4 The importance ranking from fisheries professionals 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

the seafloor is covered by cyanobacteria, and these areas have less fish and biodiversity in general, as *Cassiopea* spp., 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 additional fishing guides also highlighted this notion. Potential management recommendations

Based on the surveys from Cuban fisheries professionals and flats fishing guides, we developed nine potential management recommendations for the bonefish fishery in Cuba:

**R1** LEK should be integrated into management and aid scientists in determining bonefish PSA and migration route sites.

**R2** During perceived spawning periods, scientists should monitor spawning behaviour, collect egg samples and submit reports to incorporate PSA and migration routes within protected areas or no-take zones.

**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.

**R4** Expand flats fishing ports to new areas in the country to aid in bonefish conservation and management.

**R5** MINTUR and MINAL need to share economic information about bonefish C&R fishing and commercial fishing and initiate legal protection and management mechanisms for bonefish.

**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.

**R7** Compliance and education programs should be developed and opportunities for alternative live-lihoods determined for those displaced by MPA designation.

**R8** Alongside MINAL, third-party institution collaboration should be encouraged to aid in scientific and compliance monitoring of vulnerable flats fishing grounds and species.

**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 stake-holder groups.

Management recommendation refinement

Potential management recommendations were examined to determine their actual feasibility within the context of the Cuban fishery community. Five fishery experts stated whether they agree with a recommendation meeting the criteria outlined by the interviewer - achievability, feasibility and respectful of local context (Fig. 5). In addition, experts provided feedback on each recommendation and discussed the challenges of each with additional aspects to consider (Table 5). Where management recommendations were deemed 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, and lack of enforcement and adaptive management may hinder the recommendations' success. For example, in relation to expanding the recreational 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 concessionaires that constitute 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).

Experts described the challenges that may arise (related to economic, social or governance aspects) with the implementation of the potential management recommendations (Table 5). For example, many experts were critical of R4 due to the difficulties (cultural, bureaucratic and logistical) that would occur from expanding fly-fishing ports in the country. If expansion is not embraced by local communities, conservation of flats species would



Fig. 5 The number of experts who deemed each potential management recommendation as meeting the criteria (achievable, feasible, respectful of local context) for implementation in Cuban fisheries management and research

not be supported by those displaced by new recreational flats fishing establishments and compliance would be difficult to obtain for future management strategies. Alongside identified challenges shown in Table 5, experts provide 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 with MINAL. First, the Ministry of Tourism (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 in Cuba". 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 with 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

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processes to begin with the support from MINAL and MINTUR.

### Discussion

Fisheries professionals and fishing guides reported that more is needed to effectively manage bonefish in Cuba. Effective management in part means working within the current government structure and processes, if bonefish PSAs are to be prioritized in Cuban fisheries management. This research demonstrates the value of including local guides, LEK and the context of MPAs in bonefish management. As LEK suggests that some bonefish PSAs and migration routes fall within existing MPAs, a good first step to revise management within these MPAs would be to foster collaboration between researchers and experienced fishers to positively identify these sites. Fisheries professionals indicated that spatial protection measures would be most effective for conserving bonefish at spawning sites. However, they emphasized that additional, complementary management actions and

Recommendation	Challenges	Source
R1	<ul> <li>Governance and social</li> <li>Integrating and supporting management to implement and integrate LEK into management</li> <li>Fisheries authority needs to strengthen relationships with coastal communities</li> <li>Public participation is extremely poor, as avenues do not exist for the public to share ideas, criticism, feedback, or concerns</li> </ul>	- 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	<ul><li>Expert 1</li><li>Expert 2</li><li>Expert 3</li><li>Expert 4</li></ul>
R4	<ul> <li>Governance, economic and social</li> <li>Will be difficult to obtain logistical support</li> <li>Locals who target bonefish or other species in potential areas will not accept newly established MPAs</li> <li>Alternative livelihoods in guided fishing are difficult to transition into (for cultural, traditional, and bureaucratic reasons)</li> <li>Financial support is difficult to obtain</li> </ul>	- 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	<ul> <li>Governance, social, and economic</li> <li>Fishers may not report their catches or comply to regulations</li> <li>Enforcement and monitoring will be difficult because of a lack of personnel and resources</li> <li>Backlash from communities and difficulties with transitioning locals toward alternative livelihoods</li> </ul>	- Expert 1 - Expert 3 - Expert 5
R7	Social and economic - Difficult to obtain resources and finances - Fishers 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

 Table 5
 Challenges identified by experts for the management recommendations presented through the expert elicitation process.

 Expert 1 to Expert 5 are the individual experts in Caribbean and/or Cuban fisheries management

collaboration with stakeholders are needed to overcome existing challenges.

Cuban fishing guides are eager to participate in spawning-related research for bonefish. Their involvement will aid scientists in gaining vital knowledge for conservation and management of bonefish. Fishing guides provided valuable knowledge about bonefish in Cuba that should help guide spatial and temporal research and management. For example, guide LEK suggests that the spawning season in Cuba (November–July) may last longer than previously reported in The Bahamas (November–April) (Danylchuk et al. 2011; Adams et al. 2019). Additional data collection from guides and scientists through scientific sampling will test these observations. Furthermore, guides indicated that ecosystems with fewer bonefish have less biodiversity and an overabundance of crustaceans and cyanobacteria. Comparative studies between locations with abundant bonefish (e.g., JDR or Canarreos) and areas where bonefish have been overfished (e.g., Isla de la Juventud) would further test these observations and help with decision-making when selecting management options or priority areas for conservation.

Fishing guides can lead the 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. It is vital for guides and community members to be involved in management, monitoring, education and research of bonefish, the fishery and habitats (Johannes et al. 2000). Such partnerships 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 et al. 2007).

A variety of options and considerations have arisen for effectively managing bonefish spawning sites. Specifically, fisheries professionals emphasized the importance of spatial and temporal management. The creation of no-take zones or specially zoned spawning reserves within protected areas may be called for, following spawning site identification (Claro et al. 2001). In addition, species-scale fishing differences must be considered in management (Claro et al. 2019). For example, bonefish are fished at PSAs in Boca de Manatí-Turíguano (Angulo-Valdés et al. 2017); however, in Cayo Coco, bonefish are intercepted by commercial fishers during spawning migrations. Therefore, in regions where PSAs and/ or migration routes are vulnerable, spawning season closures may be more effective than only MPAs at spawning sites (Claro et al. 2019); PSAs and migration routes should be designated as no-take zones within and outside MPAs with a temporal component to incorporate spawning season and perhaps lunar phases. Adaptive, precautionary, and data-limited management — all emphasized in the Cuban Fisheries Law (2020) — would then aid in appropriately zoning sites, expanding MPA boundaries, establishing new MPAs or developing temporal catch restrictions to produce positive conservation outcomes for the fishery (Russell et al. 2012).

Fishers who are 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 (*Cynoscion 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.

In Cuba, recreational bonefish fishing occurs within MPA boundaries, and the process of identifying and managing PSAs should begin within these protected areas. Scientists should 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. 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 reef 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). A principal feature of MPAs in Cuba is to protect critical populations for species of high economic and conservation priority (Centro Nacional de Áreas Protegidas (CNAP) 2013; Claro et al. 2019). Bonefish spawning migration corridors and PSAs meet this criterion (Claro et al. 2019) but are not yet considered in MPA planning.

MPA planning and establishment should require clearly defined spatially and temporally distinct monitoring programs for bonefish PSAs and migration sites, as well as mechanisms to fund such activities (Claro et al. 2019). Within MPAs, appropriate zonation of spawning sites (spawning reserves) would aid in effective enforcement, compliance and scientific monitoring. A similar approach is found in a Belizean MPA (Glovers Reef Atoll Marine Reserve, Belize) (Strindberg et al. 2016). This Marine Reserve prioritizes spawning sites for fishes, by designating a spawning aggregation zone (where all fishing is prohibited, which overlaps with a seasonal closure zone from December-February) for regular scientific and compliance monitoring (Strindberg et al. 2016). Tourism C&R fishing fees should fund science and enforcement, even as the fishery financially contributes to local communities and national economies.

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). Fisheries professionals and fishing guides highlighted that commercial capture of the species should be reduced, as bonefish are much more valuable alive versus dead. For example, in JDR, C&R fishing for bonefish generates US\$808,574 annually, while the benefits from commercial fisheries in the surrounding areas (eight times larger than JDR) are worth less than 3% of the recreational fishery (T. Figueredo-Martín pers. communication). Globally, the economic valuation for the flats fishery in JDR is amongst the highest when compared to other fly-fishing destinations (T. Figueredo-Martín pers. communication). Habitat conservation of flats species' home ranges, spawning migration pathways and PSAs would be an investment in this economically valuable fishery by the Cuban government. Thus, the flats fishery can be sustained in perpetuity with proper investment in habitat conservation and management (Fedler 2019).

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 C&R with generally high post-release survival (Cooke et al. 2006), which also supports sustainable economies associated with ecotourism (Danlychuk et al. 2007; Adams et al. 2021). For example, JDR and Canarreos are older MPAs supported by legislation that restricts fishing for bonefish and tarpon in nearby gulfs: The Gulf of Ana María and Gulf of Batabanó (Fig. 1). 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 impact of US\$169 million, and supports more than 7800 jobs, and the fishery's per capita economic impact is double that of standard tourism (Fedler 2019). It is estimated that nationally, 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-Valdés et al. 2017). Appropriate management of bonefish PSAs and spawning migrations is an essential component of this broader need.

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 MINTUR should communicate economic and catch-related data about bonefish to enable effective management. Once economic estimates are shared between MINTUR and MINAL, bonefish economic contributions to national and local economies can be recognized. To build trust and advance management, these stakeholders must share all relevant information about flats species. 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. Third-party institutions should be encouraged to participate in research, which can aid in data-collection, funding and sharing of results. In addition, since commercial stakeholders were not included in this study, future changes to management should include stakeholder groups outside of the flats fishery.

In neighbouring states (The Bahamas, Belize and Florida (USA)), the recreational economic importance of bonefish has led to the implementation of catch restrictions of bonefish, which is limited to C&R only (Belize, Florida) or for personal consumption using hook and line (The Bahamas) (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). It is important for MINAL to recognize the importance of the flats fishery in Cuba and potentially develop opportunities to expand C&R concessions to develop alternative livelihood options for communities, which can also aid in marine conservation. The establishment of positions, such as fishing guides, would enhance surveillance on the water and limit illegal fishing. If spawning-associated harvests of bonefish continue in Cuba, reductions in size (age) at maturity and maximum sizes may continue (Rennert et al. 2019), with population-level and financial implications (Johannes and Yeeting 2001; Filous et al. 2019, 2021).

Spawning-related management will provide the highest benefit-to-cost ratio for fisheries and conservation outcomes (Erisman et al. 2017). Bonefish are vital to C&R fishing within MPAs, and conserving their spawning events should be prioritized to ensure ecosystem services provided by the species and can continue supporting many people and species in the country (Pittman and Heyman 2020). It is important to conserve bonefish PSAs and migration routes, as these spawning events offer great potential as conservation bright spots (sensu Pittman and Heyman 2020) to rehabilitate marine ecosystems, replenish fished populations and achieve fisheries sustainability (Aburto-Oropeza et al. 2011; Hamilton et al. 2011). However, if conservation efforts go beyond spawning-specific management and protection, many ecosystems and species will benefit from bonefish conservation, as bonefish are umbrella species and management can have broader positive ecosystem conservation implications (Adams et al. 2019). 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). In addition, a research priority should be to evaluate the broader ecosystem importance of bonefish in Cuba and beyond, as literature on this subject is limited; however, fishing guides and fisheries professionals have mentioned that this species is incredibly important for healthy environments.

Bonefish in the Caribbean are valuable to multiple countries and stakeholders, whether for livelihoods, ecological functions or recreational tourism (Fedler 2013, 2014, 2019). This species provides considerable income in the region, and uncontrolled exploitation of their PSAs threatens natural resources, both biologically and economically. 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 (Gonzalez-Bernat et al. 2020). It would be in the best interest for multiple nations that bonefish that spawn in Cuba are protected.

Management recommendations

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

**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 neighbouring Caribbean States should also be prioritized.

**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, as they are eager to provide support in fishery studies.

**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. In addition, outreach efforts to non-governmental organizations (NGOs) should be undertaken to further enable development of suitable management practices. In due course (e.g., with capacity development) this could expand into formal co-management arrangements.

**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.

**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 and gear restrictions. Similarly, recreational C&R fishing should be used as a tool to provide scientists with financial and logistical resources for bonefish research.

**Reduce commercial capture of bonefish** New laws should be considered and implemented to greatly reduce or halt commercial harvest of bonefish and limit harvest to personal consumption (using hook and line) to prevent overexploitation. Fishing efforts should be diverted to focus on other species in areas where commercial fishers operate to support their livelihoods.

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Author contribution MO — study creation and design, interviews, lead on manuscript writing; AA — assistance with study design and manuscript writing; FPA — assistance with study design, conducting interviews, manuscript writing; SC — manuscript writing; MB — assistance with study design and manuscript writing. All the authors contributed to the writing, reviewing and editing, and all the authors read and approved the final manuscript. **Data availability** Due to the agreement of confidentiality between the authors and interviewees, raw data are not available.

#### Declarations

**Ethics approval** This study was performed in line with the principles of the Declaration of Helsinki. Ethics approval was obtained from Dalhousie University Marine Affairs Program Ethics Review Standing Committee with a file number: MAPERSC# 2021–04.

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