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Goliath grouper *Epinephelus itajara* (Teleostei: Serranidae) in the Mexican Caribbean: local ecological knowledge and habitat use

Ninel García-Téllez · Juan J. Schmitter-Soto · Roberto C. Barrientos-Medina · Roberto L. Herrera-Pavón

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Abstract Rare species necessitate alternative survey techniques and, in the case of exploited resources, any attempt to monitor their abundance with a meaningful benchmark should also include local ecological knowledge (LEK) of local users. This study evaluates the status of Goliath grouper (*Epinephelus itajara*) in the Mexican Caribbean via LEK and also direct acquisition of data on habitat use of the species in Chetumal Bay, taking into account distribution by body size, site, and habitat. We interviewed 124 fishers about their knowledge and experience with Goliath grouper, comparing northern to southern Mexican Caribbean, as well as older vs. younger fishers. The species is a well-identified resource; fishers are able to describe many behavioral and habitat-use traits, but they find it difficult to discern males from females and juveniles from adults. The fishery is opportunistic and the capture is commercialized and consumed only locally. The species has declined over the last decades, the probable cause being the increase in the number of fishers and boats, as well as the use of harpoon by divers. In addition to the interviews, 54 specimens were recorded in Chetumal Bay, standard length 517–1613 mm. Goliath grouper preferred submerged sinkholes and caves, locally called "pozas," with water temperature of 23–31 °C and salinity of 4.5–30.0 psu, 1.5–40.0 m deep. Although access to "pozas" can be dangerous—a fact that could favor viability of Goliath grouper—even in these sites, the fishery extracts young and subadult animals, probably affecting population dynamics.

Keywords Long-lived fishes · Conservation · Management · Distribution · Habitat use · Artisanal fisheries

N. García-Téllez
Comisión Nacional de Áreas Naturales Protegidas, Reserva de la Biosfera Barranca de Metztitlán, Metztitlán, Hidalgo, Mexico

J. J. Schmitter-Soto (✉) · R. L. Herrera-Pavón
El Colegio de la Frontera Sur, Av. Centenario km 5.5, 77014 Chetumal, Quintana Roo, Mexico
e-mail: jschmitt@ecosur.mx

R. C. Barrientos-Medina
Universidad Autónoma de Yucatán, Mérida, Yucatán, Mexico

Introduction

Research and monitoring of biological diversity are more difficult in the ocean than in land. Because of the sheer extension of the sea, marine life is often hard to reach (Ogden 1992). This situation often causes extinction risks to be underestimated; Roberts and Hawkins (1999) presented the case of 13 marine species, from different taxonomic groups, which are close to extinction or already extinct.

A majority of marine fishes live in tropical waters, about 40% of them in the coastal zone. Much of the ecological information on these species is based on fishery studies, aimed at determining optimal

commercial exploitation, which requires basic understanding of population dynamics, growth and reproduction, size and age, mortality, and movements (Lowe-McConnell 1977). Other investigations are based on direct underwater observations or in situ experiments (e.g., Paula et al., 2018).

Most species are rare, either because of limited distribution, habitat specificity, low population density, or a combination of these factors (Rabinowitz et al. 1986). Rarity makes species particularly prone to extinction by habitat alteration, overexploitation, or other reasons (Halffter and Ezcurra 1992).

The complexity of research in the sea, the rarity of many species, and the habitat use that varies according to life stage make conventional evaluation of populations difficult to apply satisfactorily for some coastal fishes (Coleman et al. 2000). As a consequence, many fishery resources are underdocumented; classical models refer to large-bodied, very mobile species, which often have a complex social structure, which can be difficult to study, notwithstanding its importance for such basic parameters as sex ratio and age at maturity (Vincent and Sadovy 1998).

The status of reef fish populations is often unknown, but the few species that have been analyzed show signs of overexploitation (Coleman et al. 2000). In North America, 13 species of serranids (groupers) have been assessed as endangered (Musick et al. 2000), in the genera *Epinephelus*, *Mycteroperca*, and *Paranthias*. Groupers are usually long-lived and protogynous (Helfman et al. 2009). At least six species of *Epinephelus* are commercially important; the largest one, reaching 2.5 m in total length and a weight over 300 kg, is the Goliath grouper, *E. itajara* (Lichtenstein 1822). This fish, known as "cherna" in the Mexican Caribbean, dwells along both coasts of the Atlantic Ocean, from Florida to Brazil and from Senegal to Angola (Craig et al. 2009), in shallow waters, inside bays and estuaries, and to a depth of 45 m in the front reef. The species can live to be 37 years old, and it matures at 5–6 years of age (Bullock et al. 1992). Length structure is bimodal, the modes corresponding to females when young and to males later in life. Adults are solitary, inhabiting caves and crevices in the reef and preying mainly on macrocrustaceans, conch, and octopi (Sadovy and Eklund 1999). Goliath groupers are territorial and able to emit sounds when threatened (Colin 1994).

The Goliath grouper is an example of a historically overexploited resource for which data are scant, except in Florida, where information is available for some decades (Koenig et al. 2011), illustrating a pattern of recovery since the commercial extinction declared in 1990 (but see also McClenachan, 2009). Studies with more limited time series, or with only isolated assessments (often for the status of reproductive aggregations), exist for Belize (Graham et al. 2009), Cayman Islands (Whaylen et al. 2004), and Cuba (Pina-Amargós and González-Sansón 2009). In the case of Mexico, official reports lump together catch data for all groupers ("meros"); however, Aguilar-Perera et al. (2009) escaped this situation in the Gulf of Mexico of the Yucatan by analyzing logs from two fishing cooperatives (not the official data) for the period 1999–2004 and interviewing elderly fishers from two landing sites; they concluded that the resource was severely dwindling, as also did Bravo-Calderón et al. (2021) for the same region.

The "cherna" is not the only case of a fishery that lacks appropriate historical data, a situation far too common in developing countries. "Baselines" are too recent to be realistic or reliable references, and the uncertainty or even absence of data must be openly confronted (Johannes 1998). One way to do this is to take into account traditional or local ecological knowledge (LEK), i.e., the "understandings and the know-how arising through time from experiences and observations regarding the environment, behavioral attributes of animals, and ecological dynamics" (Davis and Wagner 2003). Data provided by LEK may be anecdotic and without formality, but they have been successfully used to infer former distribution and even pre-exploitation biomass, so they may be regarded as a palliative to the "shifting-baseline syndrome" (Pauly, 1995). Anecdotal information has been often questioned, arguing cultural bias and fishers' memory distortion due to the time elapsed; nevertheless, it is clear that fishing communities do know their ecosystems and have acquired valid preliminary ecological information on their resources. Moreover, LEK may be in many cases the sole way to access these data (Poizat and Baran, 1997).

The present work is aimed at characterizing the status of Goliath grouper in the Mexican Caribbean, mostly using information from fishers and fish dealers (LEK), but with emphasis on Chetumal Bay, adding directly acquired data on the species distribution and habitat use by size class. Changes in the status of the resource are inferred from the vision of two generations of fishers, from villages throughout the State of Quintana Roo.

Material and methods

Study area

The Caribbean versant of Mexico, eastern Yucatan, state of Quintana Roo, is a nearly flat karstic platform, marine in origin, and more recent than the rest of the peninsula. Its 860-km-long coastline includes a variety of habitats, including the fringing coral reef that constitutes the northern half of the Mesoamerican Reef Barrier; there is a shallow reef lagoon of varying width (up to 1000 m near the Mexican-Belizean border), mainly covered by seagrass, with isolated coral patches (Núñez-Lara and Arias-González 1998).

Along this coast, there are three main bays: Ascensión, Espíritu Santo, and Chetumal. Chetumal Bay (shared with Belize, where it is called Corozal Bay) is roughly triangular, about 67 km long and 20 km wide (Fig. 1). Its mean depth is 3 m, but there are scattered sinkholes (locally termed "pozas"), some up to 42 m deep (Carrillo et al. 2009a). Mangroves are the dominant coastal vegetation.

Chetumal Bay is the estuary of the Hondo River. Nevertheless, it displays no true estuarine dynamics, because salinity is rather constant; the river mouth and minor streams induce small oligohaline zones, and the extreme southwest is polyhaline, due to the influence of the Caribbean Sea through the Bacalar Chico channel and other passages between Belizean keys, whereas the rest of the bay is mesohaline (Carrillo et al. 2009b). Mean surface temperature is 28 °C, reflecting the warm humid climate of the region, with summer rains and an annual precipitation that follows a south-to-north gradient of 1000–1500 mm.

According to economic development, there are three sharply different zones: (a) the north, including Cancún, centered in intense tourism and a mostly immigrant population; (b) the center, where Mayan villages live off cultivation of maize and other produce, largely separated from the sea by the Sian Ka'an Biosphere Reserve, with the bays of Ascensión and Espíritu Santo, and (c) the south, where most people are employed in public administration or in commerce (César Dachary et al. 1992), and including Chetumal Bay.

In spite of the transition to tourism over the last decades, stronger in the north zone but present as well in the south, artisanal fishing is still a relevant activity, with several longstanding cooperatives, most of them centered in lobster and queen conch, but also gill-netting or long-lining groupers, snappers, sierras, and barracuda, among others (Espinoza-Ávalos et al. 2009). There is also an increasing catch-and-release recreational fishery, targeting tarpon, permit, and bonefish, species that move regularly between habitats in the area (Perez et al. 2019).

LEK: Mexican Caribbean

We interviewed fishers in ten coastal communities: Holbox, Isla Mujeres, Cozumel, and Tulum, in the north, and Punta Allen, Punta Herrero, Xcalak, Mahahual, Chetumal, and Calderitas, in the south (Fig. 1). After this geographically stratified sampling, a first interviewee was contacted directly, who then referred us to other informants, until no new information was provided or no more fishers were available in the given community (i.e., a snowball approach: Biernacki and Waldorf 1981). A multiple-choice questionnaire (see Appendix 1) was verbally responded by both active and former fishers. Questions were classified into three subjects: first, the degree of knowledge about the species: common names, behavior, identification of sex and stage, and reproductive activity; second, distribution, rarity, habitat, seasonality; and the last part of the questionnaire concerned the fishery: captures, length frequency, fishing gear, and commercialization. Moreover, every fisher was asked to mention a personal anecdote related to the "cherna" and its fishery. In addition, all major fish markets and shops in Chetumal City were visited and another questionnaire applied (see Appendix 2) to assess tendencies in the sales of this resource.

Results were classified by zone (north vs. south) and experience (less vs. more than 20 years fishing in the region). A corner test for association was applied to experience and age (i.e., a graph of both variables, divided in quadrants by the respective medians, the median age being 41 years: Olmstead and Tukey 1947). To detect interactions, we built contingency tables (see Appendix 3) with three dimensions ($n \times 2 \times 2$), for the number of possible responses (n), zone, and experience. When differences were detected, a test of partial independence was performed, to check which variables established the pattern (Zar 1998). For anecdotes, experiences judged to be similar were grouped and related to information or behavior mentioned in the literature, thus attempting to verify or explain the fishers' reports.

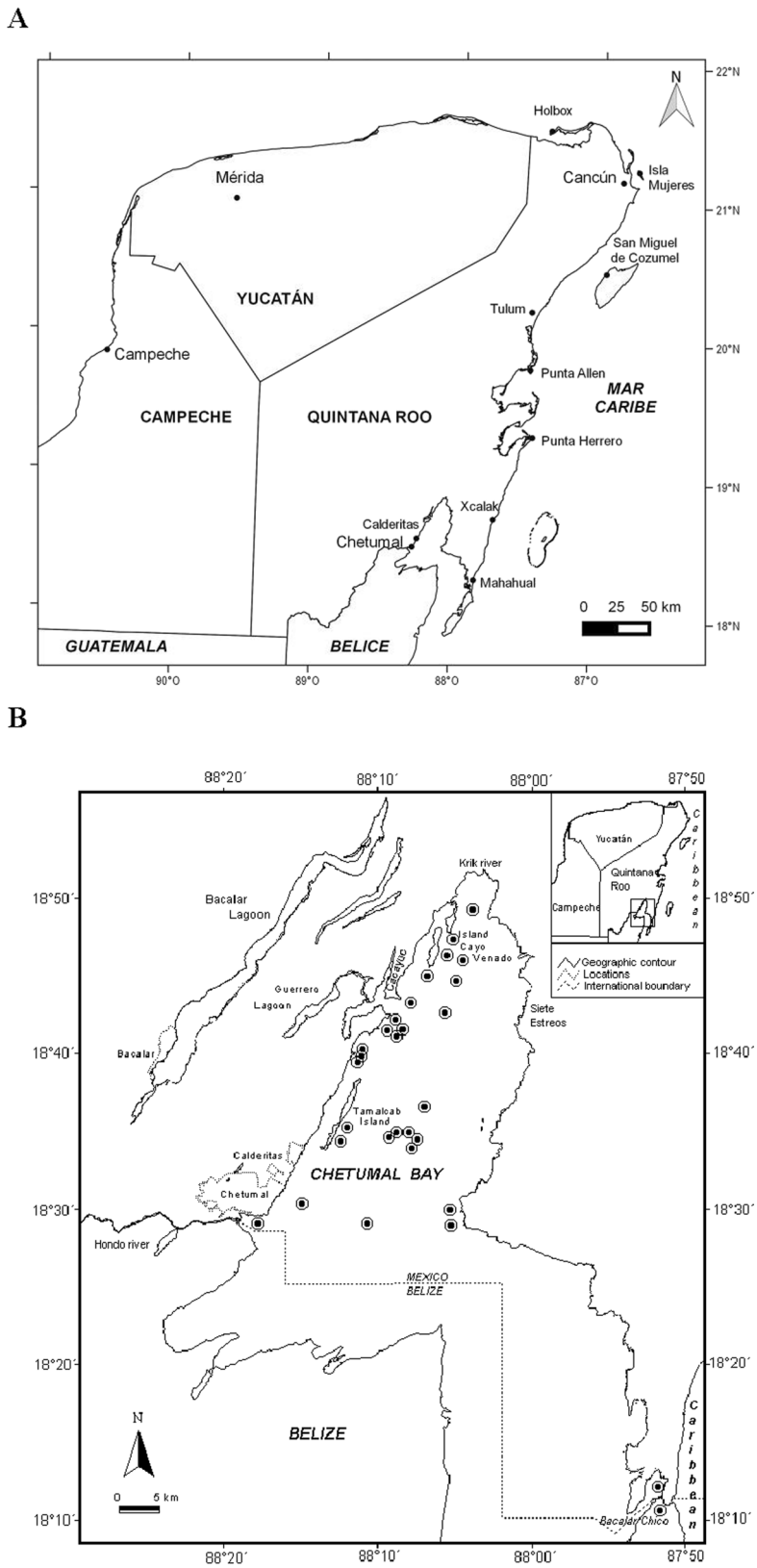


Fig. 1 Study area. **A** The Mexican Caribbean coast, eastern Yucatan peninsula, showing the ten fishing communities where interviews were held. **B** Chetumal Bay, with the sites where Goliath grouper was captured

Sampling: Chetumal Bay

We searched for Goliath grouper in the Mexican side of Chetumal/Corozal Bay, between September 2000 and November 2001. Records were either direct observations (by snorkeling or scuba-diving) or data provided by fishers working in the bay, who catch the animals with hook and line, long-line, and spear.

The captured fishes were weighed. Because we often had no access to the specimen, we had to estimate length from the weight data provided by the fishers, using the (ungutted) weight-length relationship provided by Bullock et al. (1992): $W = 1.31 \times 10^{-8} L^{3.056}$, where W = weight (g) and L = length (mm).

The site of capture was positioned with a GPS. Temperature and salinity (bottom and surface) were measured with portable devices. Habitat was described and classified by depth, vegetation, and physiography into four types: mangroves, ledges, caves, and "pozas." Ledges are laminar projections that form in the bay bottom from the partial dissolution of the calcareous matrix; caves are larger cavities formed by the division (total or partial) of the vault in the bay bottom; "pozas" are deep submerged karstic sinkholes. Sampling effort by habitat was balanced, although fishers provided more data from "pozas."

In order to determine if the species preferred a habitat in particular, a multinomial chi-square test (Zar 1998) was applied on the relative frequency of observation in each one of the four habitat types. We visited most frequently the shallower habitats (ledges, caves, and mangrove), due to their facility of access; on the other hand, the fishers provided information on "pozas," sites that by their depth and visibility conditions were not always accessible to direct observation by unexperienced divers.

For all statistical analyses, we used package MVSP (Kovach 2007); confidence level was $p < 0.05$.

Results

Traditional knowledge in the Mexican Caribbean

We interviewed 124 fishers, aged 18 to 84 years old (mean 43 ± 13 years, s.d.) and years of experience, 2 to 75 (24.5 ± 13.6). The fishing communities were visited during 2000 and 2001.

All fishers recognized the species by two vernacular names: "cherna" and "guasa." However, the preferred name is associated with experience and zone ($\chi^2 = 25.28$; p < < 0.001; df 4). The more experienced fishers in the northern zone prefer the term "guasa," whereas in the south, the choice is "cherna," in addition to the English name "jewfish."

Interviewees identified the species as mild-tempered ($\chi^2 = 6.01$; ns; df 4), often coming close to divers because of "curiosity"; occasional aggressive behaviors were associated with individuals cornered in caves or previously speared. Observations of Goliath grouper as isolated individuals or with other fish, either congeners or other species, varied according to zone ($\chi^2 = 23.72$; $p < 0.05$; df 7); both experience groups considered the "cherna" mostly a solitary animal, but fishers in the north zone more commonly found them in schools, and less frequently also with other fishes.

The ability to discriminate males and females was also related to the interaction of zone and experience ($\chi^2 = 14.30$; $p < 0.05$; df 4). In the south, both experience groups declare they cannot distinguish the sexes, but in the north, there are veterans that can ($\chi^2 = 11.17$; $p < 0.05$; df 3), based on size, color, and the presence of ova.

The chance to witness reproductive events differed as well by zone and experience ($\chi^2 = 19.28$; $p < 0.05$; df 4). Northern or southern fishers of any experience have never seen such episodes during their work at sea, but in the north, there were nine fishers who claimed to have seen reproductive behavior; seven of them belong in the more experienced group, and three provide descriptions of several groupers ($\chi^2 = 17.09$; $p < < 0.001$; df 4), coinciding with published accounts of Goliath grouper aggregations (e.g., Sadovy and Eklund 1999).

Most fishers in both areas were able to distinguish adults from juveniles ($\chi^2 = 15.64$; $p < 0.05$; df 4), resorting to size, weight, and color. All fishers considered that the resource is rare ($\chi^2 = 9.40$; ns; df 4). In all communities ($\chi^2 = 2.61$; ns; df 4), specific localities were mentioned where the probability of encountering Goliath grouper was very high. There were differences by zone about the distance needed to reach the fish ($\chi^2 = 11.19$; $p < 0.05$; df 4): fishers in the south said that the grouper is close to shore, even inside bays, whereas in the north, it is necessary to get farther offshore ($\chi^2 = 7.91$; $p < 0.05$; df 3). Depth of encounter did not differ by zone or experience ($\chi^2 = 3.15$; ns; df 7).

There was no association among fishers' experience or zone and grouper habitat ($\chi^2 = 8.45$; ns; df

10). The species was most frequently encountered in caves, followed by reefs and mangroves. As for seasonality, most interviewees responded that "cherna" can be sighted all year round ($\chi^2 = 35.49$; $p < 0.001$; df 11), with a few commenting that during the rainy season, they can be found in murky water.

Goliath grouper is captured opportunistically ($\chi^2 = 2.57$; ns; df 4), according to all respondents, except for two of them, who said that they do work "continuously" with this resource. The most commonly used fishing gear was spear (52%), followed by gaff and hook-and-line (21%), with long-line being more frequent in the south (4%) and "detonator" (i.e., a pole with an explosive cartridge a the tip) in the north (4%), albeit there was no relationship between fishing gear and fishers group ($\chi^2 = 16.59$; ns; df 11).

All fishers claimed to have captured Goliath grouper at least once ($\chi^2 = 4.02$; ns; df 4), and in their opinion, it was just as difficult to catch smaller or larger individuals ($\chi^2 = 13.34$; ns; df 7). There was no relationship between fishers groups (by experience or north/south) and number of fish caught per year ($\chi^2 = 5.94$; ns; df 7); only 19% of all fishers caught more than six fish in the year previous to the interview (1999 or 2000). A few fishers claimed to have caught "several tons" of Goliath grouper in one working day (although not in the Caribbean, but in the Gulf of Mexico), but most respondents admitted that they had captured only one individual in the previous year (1999 or 2000).

In the north, regardless of the years of experience, most fishers hold the perception that Goliath grouper *has decreased*, with a minority believing that *abundance is stable*. The same pattern occurred in the south, but the difference between *decreased* and *stable* was smaller ($\chi^2 = 12.98$; $p < 0.01$; df 5). Among the possible causes for the decrease, fishers mentioned overfishing (due to an increase in fishers and boats) and "difficulty to reproduce" ($\chi^2 = 29.04$; $p < < 0.001$; df 4).

Most of the capture (52%) was for non-commercial local consumption; 42% is sold, also locally, to restaurants, hotels, and private individuals. Only 6% of the capture leaves the community, to be sold elsewhere.

Anecdotal stories tended to coincide, regardless of zone and experience group. They reinforced the results about the preliminary ecological knowledge of fishers about Goliath grouper, because the situations have also been reported in the literature (Table 1). A common expression was the sense of wonder at finding and catching such a large, seldom-seen species; for these fishers, capturing a "cherna" means an important extra income, as well as a good provision of food for the families.

Also included often in fishers' anecdotes were more violent encounters, when the fish is cornered in caves and responds by charging against the fisher. It is also a common experience that, given the size of the grouper, fishers were unable to take it on board their boats and they needed to tow it alive to shore.

In addition to individual fishers, all three fish markets and shops that sold raw Goliath grouper in Chetumal City were visited. Owners averaged 9 years in the trade, and they commercialized between 10 and

Table 1 Anecdotal data on Goliath grouper in the Mexican Caribbean that tended to be told more than once, by fishers in different areas and experience groups, and corresponds to assertions in published literature

Fishers' experience	Published reference
Docile and curious individuals	Larger individuals more likely to come very close to divers (Sadovy and Eklund 1999)
Aggressive individuals	Traumatogenic, can charge divers when cornered (Colin 1994)
Individuals repeatedly observed in the same place	Adults are sedentary; can stay at one spot for over a year (Sadovy and Eklund 1999)
Several fish together, speared from the boat without need of diving	The species aggregates to reproduce; more than 100 individuals can participate (Colin 1994)
Individuals weighing 1.5 kg inside bays	Juveniles prefer shallow habitats, such as mangroves (Sadovy and Eklund 1999)
Commonly seen next to lobster traps	Mostly carcinophagous, its diet reported to include up to 69% lobster (Smith 1971)
Make drum-like sounds	Sounds produced by muscular vibrations of the gas bladder; sound activity related to reproduction (Colin 1994)

13 fish species. Most of their products came from the Gulf of Mexico coast of Yucatan peninsula (Celestún, El Cuyo, Progreso, Ría Lagartos, Campeche) and from the Caribbean versant (Punta Herrero, Mahahual, Río Huach, Xcalak, Chetumal Bay). In spite of Chetumal City being located at the bay of the same name, products from the bay itself are rare; only three fish shops sell species from the bay with any frequency.

Notwithstanding that Goliath grouper is not a common item in the fish shops, all vendors got to sell at least one specimen in the former year, and one shop sold 15 fish in 1 year. Individual weight fluctuated from 30 to 60 kg; one of the sellers stated that "chernas" up to 120 kg in weight come from the Gulf of Mexico (State of Yucatan), whereas fish from the Caribbean weigh only up to 100 kg, and usually come from Mahahual and Punta Herrero, on the marine coast. Groupers from Chetumal Bay rarely make it to the fish shops in the city. Most fishers deal directly with restaurant owners to sell their product at the end of the working day.

All respondents coincide that more Goliath groupers were sold in the past, and that in recent years, the number of fish reaching the market has decreased. It is and always has been a very esteemed product. A 60-kg fish sells in 1 or 2 days, usually on weekends.

Habitat use in Chetumal Bay

We examined data for 54 fish in Chetumal Bay. Average weight was 2919 g (sd 223.1 g); the largest Goliath grouper weighed 9900 g and the smallest 340 g. Almost half of the sampled individuals were below the size of first sexual maturity (Fig. 2).

Specimens were located in 31 different sites, most of them in the northwestern, most internal part (Fig. 1). There was a significant habitat preference for "pozas" ($\chi^2 = 23.2$); 42.6% of the fishes were found in these sinkholes, 29.6% preferred ledges, and caves and mangroves represented 14.8 and 13.0%, respectively.

Depth of capture varied between 1.5 and 40.0 m (average 6.8, s.d. 9.5 m); average bottom salinity was 9.1 ± 7.3 psu (range 4.5–30.0 psu) and surface salinity 7.1 ± 4.9 psu (5.0–25.5 psu). Bottom temperature was 23–31 °C, with an average of 29.3 ± 2.0 °C; surface temperature was 26–31 °C, average 29.7 ± 1.1 °C. There was no clear relationship of fish abundance to these environmental variables.

Discussion

The study of species that are threatened, rare, and without historical abundance references is challenging. In particular, any study of Goliath grouper in this region poses two practical problems: absence of baseline information on its status (distribution, fishery, biology) and lack of adequate sampling techniques, given its rarity and its preferred habitats. We think that our twin approaches, LEK and direct search in

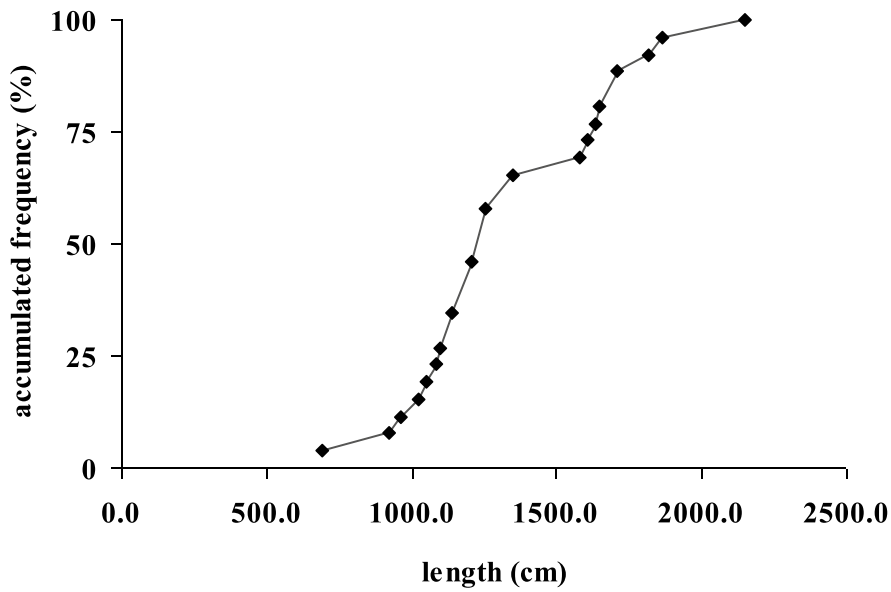


Fig. 2 Accumulated length frequency of Goliath grouper caught in Chetumal Bay. Two main modes, corresponding to juveniles and adults, are discernible

collaboration with local fishers, are complementary, and the methodology of choice for these situations (Dulvy et al. 2016). In Chetumal Bay, our work seems biased towards shallow sites; however, the interviews balanced the information for deeper environments, especially the "pozas." Our number of interviewees is almost twice that of Bravo-Calderón et al. (2021), and our number of localities is much greater, and better widespread across the Mexican Caribbean, although our information is certainly decades older.

Historically, "marine fish conservation" has actually meant preserving stocks for exploitation, thus keeping the potential, not of species or populations, but of fishery resources (Butchart et al. 2010). However, sharks, salmon, tuna, groupers, and snappers, among others, have declined in abundance and are facing sustainability and conservation problems, i.e., not just as fisheries, but as species (Vincent and Sadovy, 1998; Musick et al., 2000). Few of these have management plans, either local or international. For example, only three out of the 26 countries with shark fisheries have research and management programs for them (Safina and Duckworth 2013). Tourism development has increasingly impacted the area (Schmitter-Soto et al. 2018).

Fishery management measures include restrictions in captured volumes, number of boats, type of fishing gear, or close seasons. A problem with these approaches is that they usually fail to be effective for long-lived species. Population dynamics models generally assume a 1:1 sex ratio, they ignore growth-related sex change, they sometimes do not take into account mortality that varies by size, sex, or genotype, and they omit the importance of behavior for population fluctuations (Vincent and Sadovy, 1998; Safina and Duckworth, 2013).

Evaluation of groupers has focused on the species with greater economic value. There are management efforts for *Epinephelus striatus* (Bloch 1792), *E. morio* (Cuvier and Valenciennes 1828), *E. nigritus* (Holbrook 1855), and *Mycteroperca microlepis* (Goode and Bean 1879) in the USA, the Bermudas, and Australia (Huntsman et al. 1999). However, Sadovy and Eklund (1999) stressed the lack of basic information for Goliath grouper, a fact that explains why only Florida has a management program (Koenig et al. 2011).

Roberts and Hawkins (1999) listed 27 traits useful for determining the vulnerability to extinction of marine species. The Goliath grouper has at least 13 of these traits (for nine more, there is no information). The species is long-lived, with slow growth; it is a protogynous hermaphrodite, with site-fidelity, and (usually) not aggressive. Although their fecundity is high, age of maturity is late (5–10 years); even though natural mortality is low ($M=0.15$), growth coefficient is also low ($k=0.13$), so they are vulnerable to overfishing. The risk of overfishing is still greater because reproductive aggregation sites are close to coast and highly predictable (as reported for Florida, Belize, and Colombia), and the largest individuals are those that aggregate (Sadovy and Eklund 1999). Finally, Goliath grouper is a top predator (trophic level, 3.8 to 4.1: Froese and Pauly, 2020), which adds to its vulnerability.

For such a fishery to be sustainable, fishing mortality should be lower than natural mortality, which implies that only a fraction of the total biomass can be regularly captured (Whitlock et al. 2012). Natural mortality of groupers lies between 0.1 and 0.2, vs. a fishing mortality of 0.3 to 0.9 or higher (Coleman et al. 2000). Worse still, in Chetumal Bay, a large percentage of the captured "cherna" is below the size of first maturity. In addition to the impact on recruitment, the effect can be compounded by the (unknown) patterns of movement or migration to nearby biotopes, e.g., between the reef and the bay, although an obvious hypothesis is that at least part of the population moves to and from the reef into the bay, movements that have been documented in Cuba (Pina-Amargós and González-Sansón 2009).

In protogynous hermaphrodites facing high selective exploitation, reproduction can be significantly affected (Safina and Duckworth 2013), especially in fish that aggregate to spawn (Colin 1994). Although it is the larger individuals that participate, aggregations include fish from several age classes; however, the fishery targets the largest fish, severely modifying the age structure. On the other hand, a decrease in aggregation size is itself also a problem, because it can induce an Allee effect, due to the need to have a minimum density or number of individuals for courtship and spawning (Nemeth 2009).

Elimination of the larger individuals can imply that smaller fish reproduce earlier, which can, after some generations of natural selection, decrease the age of first sexual maturity, perhaps in addition to other genetic implications. Examples among serranids include the grouper *Mycteroperca microlepis* (Goode and Bean 1879), which changed its age at first maturity from 3.8 years old in the seventies to 2.8 years old in the nineties (Harris and Collins 2000).

We were not able to gather any geographically specific information on reproductive aggregations of Goliath grouper in the Mexican Caribbean, even for former times. The closest aggregation sites are located in Belize (Sadovy and Eklund 1999). The aggregation of a congener, *E. striatus*, which used to occur off Mahahual (Fig. 1; Aguilar-Perera and Aguilar-Dávila, 1996), has dwindled down to disappearance in the last couple of decades (Aguilar-Perera 2006).

Contrary to what we expected, the differences between fishers' viewpoints in the Mexican Caribbean were greater between north and south than between old and young fishers. One minor divergence was the vernacular name preferred, other than "cherna." The choice of "guasa" in the north may be a Cuban influence (Claro 1994), while "jewfish" in the south is likely a result of the close interaction with English-speaking Belize.

The subject where northern and southern fishers diverged the most was knowledge on the species. This can be explained because fishers in the north need to get farther away from the coast to find Goliath grouper, whereas in the south, fishing is regularly done in the inner part of the reef as well as inside the bays. This is reflected also in a greater part of the population composed by juveniles and small adults in the south.

Chetumal Bay has been recognized as a relevant nursery and feeding area for several commercial fish species (Torres-Chávez et al., 2018; Perez et al., 2019; Schmitter-Soto and Herrera-Pavón, 2019). The observed lengths confirm this for Goliath grouper, because most of the captured specimens were below the size at first maturity (males, 1.15 m SL; females, 1.20 m SL: Sadovy and Eklund, 1999). This was reported as well by Aguilar-Perera et al. (2009): historical landings in the Yucatan Gulf of Mexico versant were based on adults, except near the coast or in coastal lagoons.

The bottom of Chetumal Bay, with its fractures (ledges, caves, "pozas"), can provide additional protection for juvenile fish. Moreover, some of the "pozas" are sources of marine water in the middle of the mesohaline portion of the bay (Carrillo et al. 2009b). These "pozas" are refuges for Goliath grouper and other marine species, not only because of their depth and salinity, but also because of the often low visibility, sometimes associated with the generally strong halocline; these factors explain why access is difficult, even to experienced fishers. In fact, the "cherna" supplied to markets and restaurants in Chetumal City seldom comes from the bay, but mostly from the northern coast of Yucatan (García-Téllez 2002). When Goliath grouper are removed of their refuge by fishing, other fish soon occupy the site (fisherman B. Vellos, pers. comm.). Access to "pozas" can be dangerous—a fact that could favor viability of Goliath grouper.

Fishes living in estuaries should be able to tolerate a wide salinity range. Goliath grouper was considered marine stenohaline by Castro-Aguirre et al. (1999), who found no reports of Goliath grouper in Mexican waters below 30 psu, but our findings support its reclassification as euryhaline.

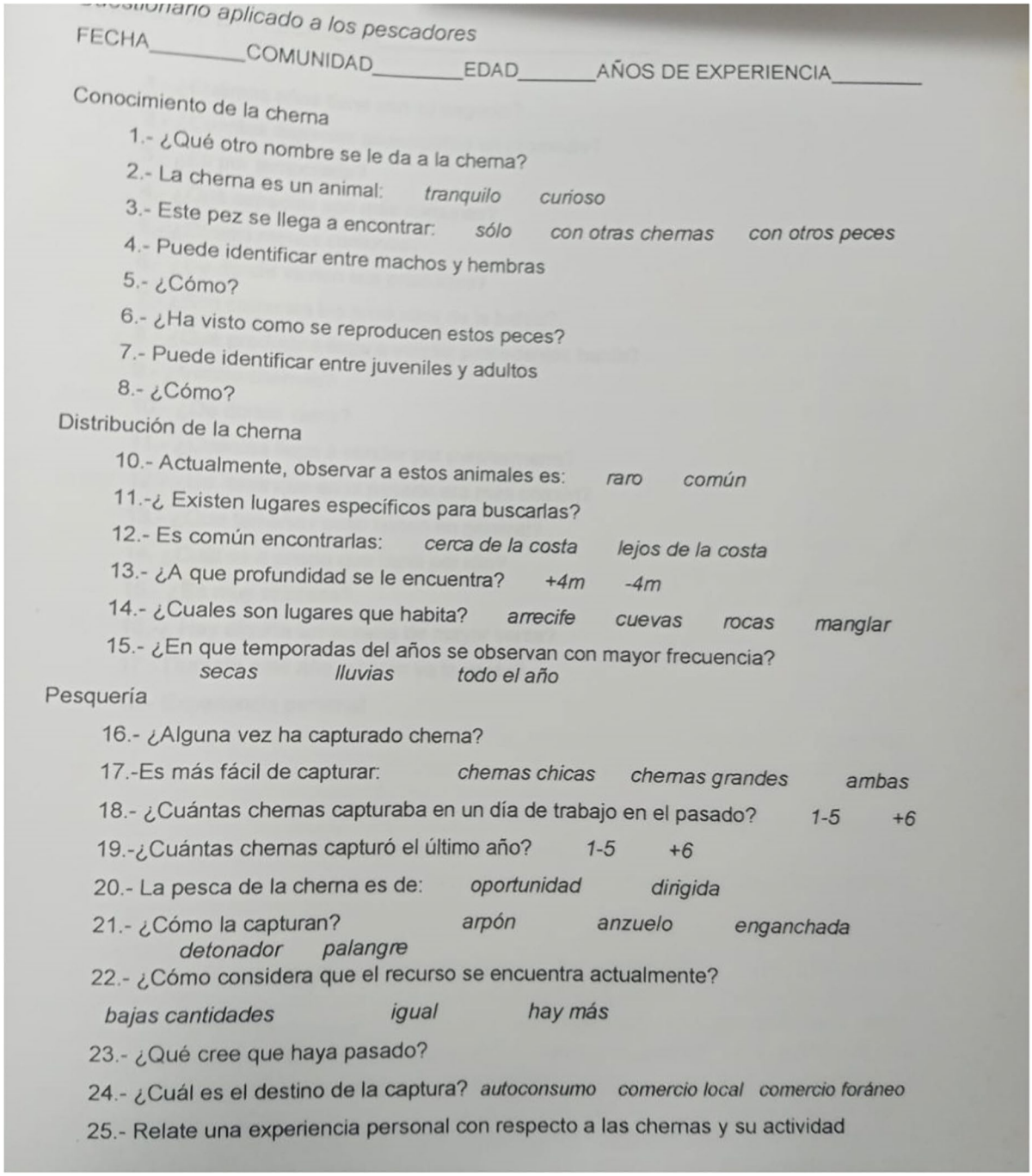
Although the data are scant, this study supports the view that Goliath grouper is a vulnerable resource in the Mexican Caribbean in general, and in particular in Chetumal Bay. The information is decades old, which adds to its value as an approximation to a baseline. In Mexico, this serranid is not yet included in threatened-species lists or protection programs, notwithstanding its decreasing populations and its status as Vulnerable in the IUCN Red List (Bertoncini et al. 2018). We concur that, regionally, its status is in fact Endangered, as ascertained by Espinosa-Pérez et al. (2015), although we believe that an assessment as Critically Endangered, as claimed by Bravo-Calderón et al. (2021), is an exaggeration, given that, as these authors themselves admit, the species is far from extirpated, at least in Chetumal Bay.

Since our data were collected, over two decades ago, fisheries management has not changed too profoundly in the Mexican Caribbean; there are now specific plans for such fishes as common snook *Centropomus undecimalis*, mullets *Mugil curema* and *M. cephalus*, and red grouper *Epinephelus morio* (CONANP 2016), but none for Goliath grouper. What has changed is the importance of tourism compared to fisheries, although this does not mean that pressure on marine resources has ceased (Schmitter-Soto et al. 2018). Marine reserves are often considered an ideal way to protect endangered species and dwindling resources (Polunin and Roberts, 1993; Birkeland, 1997; Soler et al., 2015). Nevertheless, this objective can hardly be achieved without collaboration between fishers, managers, and scientists (Fulton et al. 2018), a collaboration that often should start by tapping into the historical information that exists only in the fishers' memories. We hope that the information presented in this paper helps to preserve the traditional knowledge of these communities. The information presented in this paper could be all that is left of the older fishers' knowledge.

Appendix

Appendix 1

Facsimile of the questionnaire used to interview fishers of Goliath grouper in the Mexican Caribbean.



Cuestionario aplicado a los pescadores

FECHA_____COMUNIDAD_____EDAD_____AÑOS DE EXPERIENCIA_____

Conocimiento de la chema

1.- ¿Qué otro nombre se le da a la chema?

2.- La chema es un animal: *tranquilo* *curioso*

3.- Este pez se llega a encontrar: *sólo* *con otras chemas* *con otros peces*

4.- Puede identificar entre machos y hembras

5.- ¿Cómo?

6.- ¿Ha visto como se reproducen estos peces?

7.- Puede identificar entre juveniles y adultos

8.- ¿Cómo?

Distribución de la chema

10.- Actualmente, observar a estos animales es: *raro* *común*

11.-¿ Existen lugares específicos para buscarlas?

12.- Es común encontrarlas: *cerca de la costa* *lejos de la costa*

13.- ¿A que profundidad se le encuentra? *+4m* *-4m*

14.- ¿Cuales son lugares que habita? *arrecife* *cuevas* *rocas* *manglar*

15.- ¿En que temporadas del años se observan con mayor frecuencia?
secas *lluvias* *todo el año*

Pesquería

16.- ¿Alguna vez ha capturado chema?

17.-Es más fácil de capturar: *chemas chicas* *chemas grandes* *ambas*

18.- ¿Cuántas chemas capturaba en un día de trabajo en el pasado? *1-5* *+6*

19.-¿Cuántas chemas capturó el último año? *1-5* *+6*

20.- La pesca de la chema es de: *oportunidad* *dirigida*

21.- ¿Cómo la capturan? *arpón* *anzuelo* *enganchada*
detonador *palangre*

22.- ¿Cómo considera que el recurso se encuentra actualmente?

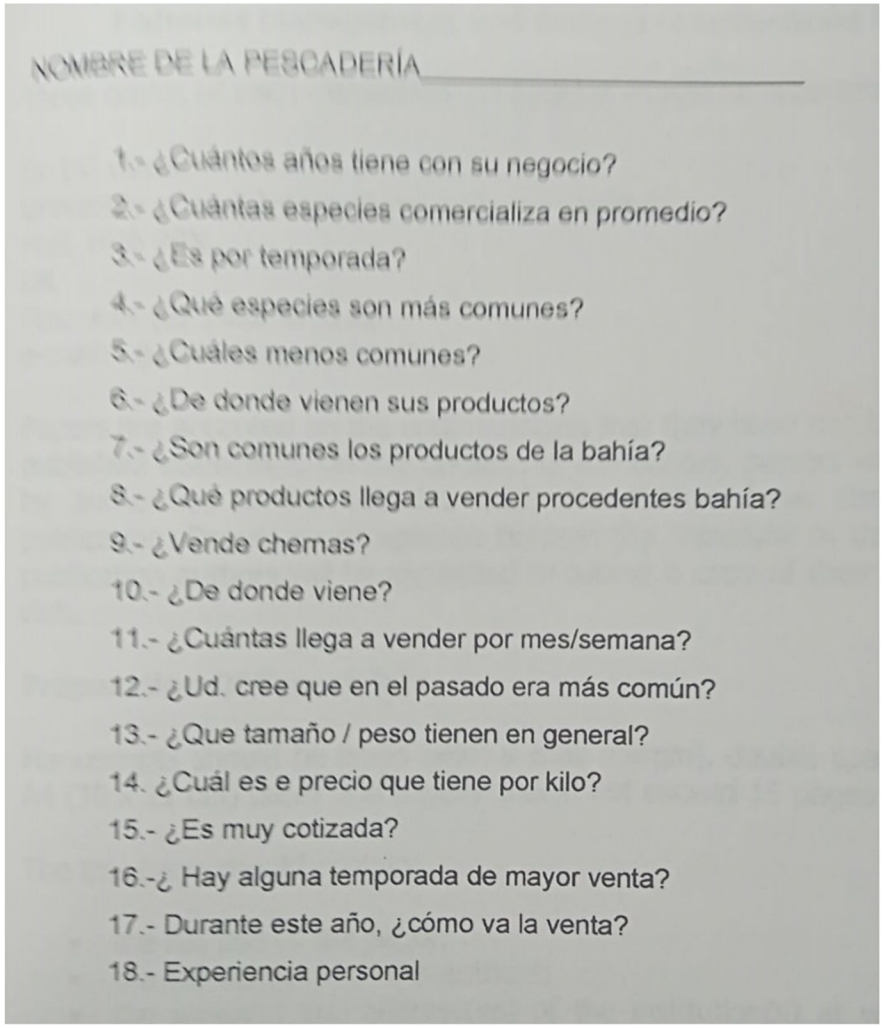
bajas cantidades *igual* *hay más*

23.- ¿Qué cree que haya pasado?

24.- ¿Cuál es el destino de la captura? *autoconsumo* *comercio local* *comercio foráneo*

25.- Relate una experiencia personal con respecto a las chemas y su actividad

Appendix 2
Facsimile of the questionnaire used to interview fish markets and shops selling raw Goliath grouper in the Mexican Caribbean.



NOMBRE DE LA PESCADERÍA_____

1.- ¿Cuántos años tiene con su negocio?
2.- ¿Cuántas especies comercializa en promedio?
3.- ¿Es por temporada?
4.- ¿Qué especies son más comunes?
5.- ¿Cuáles menos comunes?
6.- ¿De donde vienen sus productos?
7.- ¿Son comunes los productos de la bahía?
8.- ¿Qué productos llega a vender procedentes bahía?
9.- ¿Vende chernas?
10.- ¿De donde viene?
11.- ¿Cuántas llega a vender por mes/semana?
12.- ¿Ud. cree que en el pasado era más común?
13.- ¿Que tamaño / peso tienen en general?
14. ¿Cuál es e precio que tiene por kilo?
15.- ¿Es muy cotizada?
16.-¿ Hay alguna temporada de mayor venta?
17.- Durante este año, ¿cómo va la venta?
18.- Experiencia personal

Appendix 3

Contingency tables for interviews to fishers of Goliath grouper in the Mexican Caribbean.

Topic: Knowledge

1.- Common names.

	North zone		South zone	
	< 20 years	> 20 years	< 20 years	> 20 years
Cherna	7	11	22	21
Guasa	15	23	6	6

2.- Behavior.

	North zone		South zone	
	< 20 years	> 20 years	< 20 years	> 20 years
Quiet	19	31	26	20
Noisy	5	4	8	

3.- Association.

	North zone		South zone	
	< 20 years	> 20 years	< 20 years	> 20 years
Solitary	18	15	25	19
With congeners	11	11	4	10
With other fish species	4	11	1	0

4.- Sex identification.

	North zone		South zone	
	< 20 years	> 20 years	< 20 years	> 20 years
Yes	3	10	2	0
No	19	23	25	26

5.- Reproduction.

	North zone		South zone	
	< 20 years	> 20 years	< 20 years	> 20 years
Yes	3	7	0	0
No	11	18	28	28

6.- Adult identification.

	North zone		South zone	
	< 20 years	> 20 years	< 20 years	> 20 years
Yes	22	33	24	19
No	0	0	4	7

7.- Young/adult discrimination.

	North zone		South zone	
	< 20 years	> 20 years	< 20 years	> 20 years
By size	12	25	16	25
By color	1	1	4	1
By weight	3	6	1	2

Topic: Distribution

8.- Rarity.

	North zone		South zone	
	< 20 years	> 20 years	< 20 years	> 20 years
Rare	19	27	8	22
Common	2	6	10	3

9.- Places to look for it.

	North zone		South zone	
	< 20 years	> 20 years	< 20 years	> 20 years
Yes	14	21	21	20
No	7	11	6	7

10.- Distance to coast.

	North zone		South zone	
	< 20 years	> 20 years	< 20 years	> 20 years
Near	16	30	27	26
Far	16	16	8	5

11.- Depth.

	North zone		South zone	
	< 20 years	> 20 years	< 20 years	> 20 years
- 4 m	9	17	11	21

	North zone		South zone	
	< 20 years	> 20 years	< 20 years	> 20 years
+4 m	20	24	13	21

12.- Habitat.

	North zone		South zone	
	< 20 years	> 20 years	< 20 years	> 20 years
Caves	18	26	23	18
Reef	14	10	8	7
Rocks	2	4	6	4
Mangrove	0	2	13	5

13.- Seasonality.

	North zone		South zone	
	< 20 years	> 20 years	< 20 years	> 20 years
Spring	0	1	1	0
Summer	6	4	4	4
Autumn	0	3	1	0
Winter	2	8	0	1
All year long	12	13	9	9

Topic: Fisheries

14.- Have you captured Goliath grouper?

	North zone		South zone	
	< 20 years	> 20 years	< 20 years	> 20 years
Yes	22	32	28	26
No	0	1	0	0

15.- Capture feasibility by size.

	North zone		South zone	
	< 20 years	> 20 years	< 20 years	> 20 years
Small	6	10	3	6
Large	4	4	10	12
Both	8	19	8	14

16.- Goliath grouper caught per day in the past.

	North zone		South zone	
	< 20 years	> 20 years	< 20 years	> 20 years
1–5	12	12	9	12
+6	1	7	8	6

17.- Goliath grouper caught per day at present.

	North zone		South zone	
	< 20 years	> 20 years	< 20 years	> 20 years
1–3	12	19	14	12
4–6	2	6	4	1
+7	4	4	5	5

18.- Target specificity.

	North zone		South zone	
	< 20 years	> 20 years	< 20 years	> 20 years
Chance	22	32	28	25
Directed	0	1	0	1

19.- Fishing gear.

	North zone		South zone	
	< 20 years	> 20 years	< 20 years	> 20 years
Harpoon	15	26	18	26
Hook and line	8	10	4	12
Hooked stick	7	19	2	6
Blasting cap	1	3	2	0
Longline	1	1	0	0

20.- Resource frequency.

	North zone		South zone	
	< 20 years	> 20 years	< 20 years	> 20 years
Same as before	3	3	11	10
Lower	15	32	7	23
Greater	0	2	0	1

21.- Causes of decrease.

	North zone		South zone	
	< 20 years	> 20 years	< 20 years	> 20 years
Overfishing	7	23	9	16
Low reproduction	5	7	0	0

22.- Catch destination.

	North zone		South zone	
	< 20 years	> 20 years	< 20 years	> 20 years
Self-consumption	13	28	15	22
Local trade	15	28	7	14
Foreign trade	2	2	1	4

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Author contribution Study conception and design, material preparation and data collection were performed by Ninel García-Téllez, Juan J. Schmitter-Soto, and Roberto L. Herrera-Pavón. Ninel García-Téllez, Juan J. Schmitter-Soto, and Roberto C. Barrientos-Medina contributed to data analysis and commented on successive versions of the manuscript. All authors read and approved the final manuscript.

Data availability The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical approval This article is derived from the first author's M.Sc. dissertation; as such, it was approved by the research ethics committee of El Colegio de la Frontera Sur (ECOSUR) and performed in accordance with all applicable ethical standards. All applicable international, national, and/or institutional guidelines for the care and use of animals were followed.

Conflict of interest The authors declare no competing interests.

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