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Using landing statistics and fishers' traditional ecological knowledge to assess conservation threats to Pacific goliath grouper in Colombia

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Abstract

1. Groupers are vulnerable to fishing pressure largely because of their life-history traits. The Pacific goliath grouper (PGG; *Epinephelus quinquefasciatus*), the largest reef fish inhabiting the tropical Eastern Pacific region, is suspected to be subject to high levels of exploitation, but scarce information exists on their population status and the species remains classed as Data Deficient according to the International Union for Conservation of Nature (IUCN) Red List.
2. This study documents for the first time the threats to the PGG along the Colombian Pacific coast, where one of the few active fisheries for this species persists. Reconstructed landings of groupers and traditional ecological knowledge, gathered throughout several coastal villages, were used to obtain a historical and contemporary overview of the PGG status in Colombia.
3. Over the past 20 years grouper landings in the Colombian Pacific have been around 200 tons per year. Landings of PGG have averaged ~35 tons per year and are now close to matching those of the historically most landed grouper on this coast, the rooster hind (*Hyporthodus acanthistius*). The current small-scale fishery for PGG focuses on immature small individuals, with most taken from the extensive southern mangroves. Until recently fishers have captured PGG exclusively with handlines, but new fishing practices (spearfishing) and markets commanding higher prices for small individuals are increasing the extinction risk for the PGG.
4. The exploitation of PGG in the Colombian Pacific may not be as severe as in other countries where severe population declines are suspected (e.g. Mexico). Low coastal human population density and the presence of relatively intact mangroves, essential habitat for juvenile fishes, contribute to the persistence of PGG populations throughout the Colombian Pacific.
5. National and regional conservation and management measures should identify and protect mangrove nurseries and offshore spawning aggregation sites. Well-enforced protected nurseries and spawning aggregation sites will then protect juvenile and adult PGG, improving the sustainability of this fishery.

KEYWORDS

coastal, Colombia, conservation evaluation, Eastern Pacific, endangered species, fish, fishing, groupers, mangrove, red list, reef, urban development

1 | INTRODUCTION

Groupers (Epinephelidae) are a group of 168 species of small- to large-bodied teleost fishes that inhabit coastal habitats, where they play important roles in coastal ecosystems as top predators (Craig, Sadovy de Mitcheson, & Heemstra, 2011; Hixon & Carr, 1997; Stewart & Jones, 2001). Under increasing pressure from coastal fisheries, groupers are in demand because of their high value in local and international markets (Craig et al., 2011; Heemstra & Randall, 1993). Currently, 12% of groupers worldwide are considered under threat of extinction (i.e. Critically Endangered, Endangered, or Vulnerable), with another 13% considered as Near Threatened. Using the International Union for Conservation of Nature (IUCN) Red List criteria, insufficient data exist to complete any assessments for 30% of the species, and these are listed as Data Deficient (Sadovy de Mitcheson et al., 2013).

Only four grouper species exceed 2 m in total length, including the giant grouper (*Epinephelus lanceolatus*), Atlantic and Pacific goliath groupers (*Epinephelus itajara* and *Epinephelus quinquefasciatus*, respectively), and the Warsaw grouper (*Hyporthodus nigritus*) (Craig et al., 2011). The Atlantic goliath grouper (*E. itajara*) is the largest reef fish in the Western Hemisphere, and was long considered a single species with a distribution on both tropical coasts of the Americas (Eastern Pacific and Western Atlantic, including the Caribbean). Atlantic and Pacific goliath groupers are now considered two genetically distinct yet morphologically similar species, divided by the Isthmus of Panama (Craig et al., 2009).

The Atlantic goliath grouper is assessed as Critically Endangered based on its vulnerable life-history characteristics and the observed population declines in its distribution range over the past three generations (Craig et al., 2011; Graham, Rhodes, & Castellanos, 2009; Sadovy & Eklund, 1999). The species is currently protected and harvesting is prohibited in the USA and Brazil; however, they are not protected in many of the other countries in which they occur. Goliath groupers in Colombia (Caribbean and Pacific coasts) were once assessed as Critically Endangered based solely on anecdotal information from the Colombian Caribbean coast (Mejía & Acero, 2002). After the recognition of Atlantic and Pacific populations of goliath groupers as distinct species (Craig et al., 2009), a regional assessment of the Pacific species was completed in 2011 (Erisman, 2011), and this suggested that the Pacific goliath grouper (hereafter PGG) had also suffered severe declines over the past three decades throughout its geographical range (from Mexico to Peru). The assessment acknowledged the scarcity of fisheries-independent data to determine the species abundance, and relied on data for species population size and current threats from the Gulf of California in Mexico and Panama. Information from other countries was absent (Erisman, 2011; Polidoro et al., 2012). For this reason, the PGG is now among the 50 species of groupers for which a lack of sufficient information prevents an adequate evaluation of populations (i.e. species listed as Data Deficient; Sadovy de Mitcheson et al., 2013). Despite documenting an active fishery for this species in Colombia (Baos, Castellanos-Galindo, Chong-Montenegro, Tompkins, & Zapata, 2016), a recent national assessment concluded that there is still insufficient information to list *E. quinquefasciatus* under any other Red List category than Data Deficient (Castellanos-Galindo, Baos, & Zapata, 2017).

Assuming that Atlantic and Pacific goliath groupers have similar life-history characteristics, it can be expected that the extensive mangrove areas in the Eastern Pacific, especially those in the Colombian and Panamanian Pacific rainy coasts, may be a preferred habitat for juveniles (of <110 cm total length, TL; Frias-Torres, 2006; Koenig, Coleman, Eklund, Schull, & Ueland, 2007; Sadovy & Eklund, 1999), which will later migrate to deeper areas in adjacent reefs. The mangrove areas in this region sustain important small-scale fisheries targeting largely shallow-water estuarine fish species, potentially including small-sized PGGs. The degree of pressure placed on this species by these small-scale fishery fleets, however, is not yet known. Investigating the dynamics of these fisheries is therefore likely to bring insights into the fishery and biology of PGG in the Eastern Pacific.

In light of significant data gaps on fish and fisheries, traditional ecological knowledge (TEK) or information gathered from fishers about the local marine environment (Johannes, 1998) has the potential to inform fisheries science (Hind, 2015). Johannes (1998) and Heyman and Graham (2000a, 2000b, 2000c) encouraged decision makers and scientists to validate and value TEK for marine species and fisheries management and conservation. Beaudreau and Levin (2014) compared TEK about fish abundance trends in Puget Sound, USA, from different resource users in an attempt to synthesize qualitative and quantitative knowledge about data-poor species. Combining such valuable information from resource users with standard quantitative fisheries data could be a better way to correctly reconstruct marine species' history of exploitation, without the risk of falling into 'shifting baseline syndrome' (Gaspari, Bryceson, & Kulindwa, 2015; Sáenz-Arroyo, Roberts, Torre, Cariño-Olvera, & Enriquez-Andrade, 2005).

This study attempts to provide a retrospective and up-to-date account of Colombia's PGG fishery, probably one of the last areas in the Eastern Pacific where an active fishery for this species exists (Figure 1). The study involves: (i) a reconstruction of the official landing statistics for groupers; (ii) monitoring of landings at the main small-scale fishery port between 2012 and 2015; and (iii) TEK gained from fishers along coastal areas with different levels of anthropogenic influence. The combination of these three sources of information provides the first account of the threats that this species faces in the Colombian Pacific, and provides much needed fisheries and biological information to determine the national and regional extinction risk for this species (i.e. IUCN red listing in the tropical Eastern Pacific region).

2 | METHODS

2.1 | Study area

Colombia is located in north-western South America, and is bordered by the Pacific Ocean and the Caribbean Sea (1400 and 1600 km, respectively; Correa & Morton, 2010). The Colombian Pacific coast has a narrow continental shelf and is dominated by extensive mangrove forests (predominantly *Rhizophora* spp. trees) in the south (Castellanos-Galindo, Cantera, Saint-Paul, & Ferrol-Schulte, 2015) and rocky shores in the north, with very few coral reefs (Glynn & Ault, 2000). Annual rainfall fluctuates between 3000 and 10 000 mm along the coast (Correa & Morton, 2010; Poveda & Mesa, 2000). Human

FIGURE 1 Goliath groupers captured by speargun fishers between 1990 and 2015 at different localities of the Colombian Pacific coast: (a, b) individuals captured on the northern coast (Nuquí and Bahía Solano); (c, d) individuals captured on the central coast (near Juanchaco)

development on the Colombian Pacific coast is extremely low compared with the Caribbean (Ramírez & de Aguas, 2015), with only two access roads connecting inland cities to the coast (Buenaventura and Tumaco), and with all other areas accessible only by boat or small airplanes (Figure 2).

2.2 | Marine fisheries in Colombia

Despite reports, the actual overall fishery catches in Colombia (Caribbean and Pacific) may be twice the numbers reported by the country to the Food and Agriculture Organization of the United Nations (FAO), although they are relatively small in a global context and contribute relatively little to the GDP of the country (less than US $230 million per year in gross revenues; Wielgus, Zeller, Caicedo-Herrera, & Sumaila, 2010). Small-scale fisheries are currently responsible for the majority of the seafood that is consumed in the country, with gross revenues for this sector of the Colombian Pacific generally in the range of US $10–20 million per year. A major problem for fisheries management in Colombia is that official landing statistics combine multiple species into single categories (e.g. 'groupers'), thereby complicating or rendering impossible species-level assessments (Wielgus et al., 2010). This problem holds true for Pacific Colombian groupers that are frequently lumped into the category 'meros, chernas, and cabrillas', despite comprising a group of between eight and 10 species.

2.3 | Reconstruction of historical landings and recent monitoring

As an initial step, 'grouper' (i.e. the 'meros, chernas, and cabrillas' category) and PGG landings from the Pacific coast were reconstructed from data collected by the Colombian Fisheries Authority [Ministry of Agriculture and Rural Development, Instituto Nacional de Pesca y Acuicultura (INPA), Instituto Colombiano de Desarrollo Rural (INCODER), Instituto Colombiano Agropecuario (ICA), and Autoridad Nacional De Acuicultura Y Pesca (AUNAP)] from 1981 to 2015 (MADR & CCI, 2011; Pereira-Velásquez, 1993). These data correspond mainly to the three main fish landing ports on the Colombian Pacific coast where the Fisheries Authority undertakes monitoring, i.e. Tumaco, Buenaventura, and Bahía Solano (Figure 2). This information was complemented with detailed monitoring of PGG landings at the main landing sites in Buenaventura from 2012 to 2015. During this period, PGG landed at Pueblo Nuevo – the main landing site for small-scale fisheries in the Colombian Pacific – were measured (TL, to the nearest

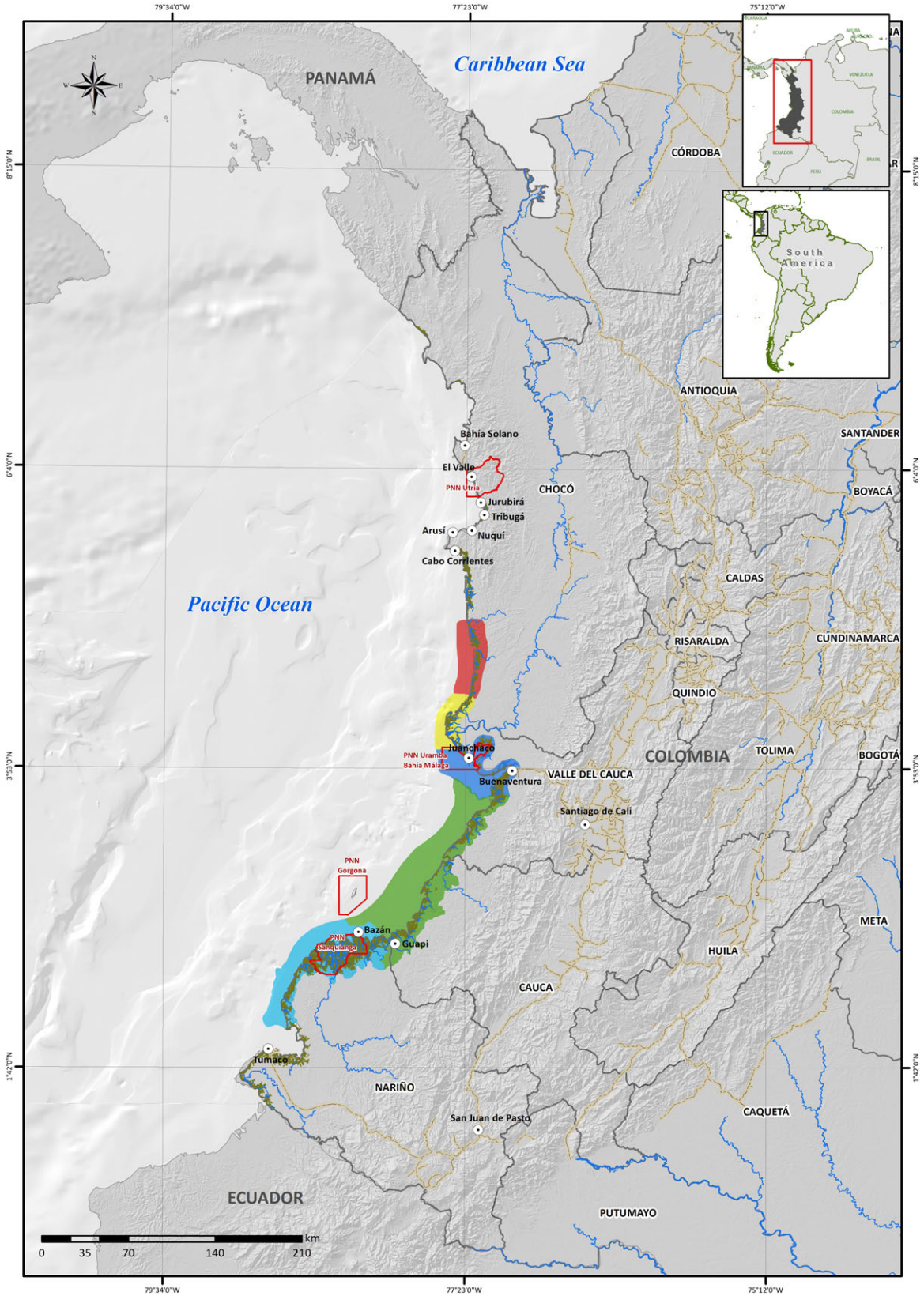

FIGURE 2 Map of the Colombian Pacific coast. Mangrove areas along the coast are indicated in green. National Parks (PNNs) are the areas in red. Shadowed areas correspond to Pizarro (red), San Juan (yellow), Juanchanco (dark blue), Naya (light green), and Sanquianga (light blue)

0.1 cm) and weighed (to the nearest 0.1 kg). The reconstructed historical landings allowed an evaluation of the magnitude of grouper catches in the Colombian Pacific over time, whereas detailed monitoring between 2012 and 2015 provided insights into the size structure of PGG landings and the predominant fishing grounds along the Colombian Pacific coast. Based on these data, five broad areas along the Colombian Pacific coast were defined (Juanchaco, Naya, Pizarro, San Juan, and Sanquianga; Figure 2).

2.4 | Traditional ecological knowledge

Information from fishers capturing PGG was gathered at eight coastal villages (northern region: Bahía Solano, Tribugá, Nuquí, Jurubirá, El Valle, and Arusí; southern region: Bahía Málaga and Bazán) along the Colombian Pacific coast. Semi-structured interviews were used following an adaptation of the survey methods used by Gerhardinger, Marenzi, Bertoncini, Medeiros, and Hostim-Silva (2006) in Brazil to obtain TEK for the Atlantic goliath grouper. This ensured the comparability of fishers' attitudes between Brazil and Colombia. After visiting each village and talking to recognized local leaders, fishers with experience in fishing PGG were approached and interviewed. Topics covered during interviews focused on: (i) the fisher's general information and habits; (ii) knowledge of the biology and ecology of PGG; (iii) perceptions of PGG conservation; and (iv) the socio-economics of PGG fisheries (Table 1).

3 | RESULTS

3.1 | Reconstruction of historical landings

Groupers in the Colombian Pacific are currently almost exclusively targeted by small-scale fishers. Total grouper landings (category 'meros, chernas, and cabrillas') over the reconstructed period were extremely variable, probably reflecting a lack of monitoring by fisheries authorities in some years. For example, low landing values in 2002 and 2012 were most likely the result of very limited monitoring during transitions in management responsibilities between different government agencies. Nevertheless, landings for this group for most years during 1981–2015 were below 250 t (mean = 213.6 t, standard error = 34.9 t; Figure 3). *Hyporthodus acanthistius*, the rooster hind (*cherna roja* in Spanish), together with the PGG *E. quinquefasciatus* ('mero') have been the two most important groupers landed in the Colombian Pacific since at least the year 2000. According to the national fishing statistics, between 2012 and 2015 these two species accounted for 64–93% of all grouper landings. The average annual landings of rooster hind and PGG in 1995–2015 were 68.8 ± 4.6 t (±SE) and 34.5 ± 6.0 t, respectively (Figure 4). The importance of both rooster hind and PGG in the overall landings of grouper, however, has changed in recent years (since 2009). Whereas rooster hind landings between 1995 and 2000 were between two- and ten-fold higher than those of PGG, in the last 8 years landings of both species have been very similar, sometimes being even higher for PGG (e.g. 2009 and 2010; Figure 4).

3.2 | Monitoring of fish market landings in Buenaventura

From July 2012 to December 2015, a total of 1981 PGG landed in the fish market of Pueblo Nuevo were measured and weighed. The total weight of grouper landings was 14 867.6 kg. Sizes ranged from 11.3 to 190.5 cm TL and from 0.3 to 110.0 kg in gutted weight. Mean TL and weight (±SE) were 72.2 cm (±0.5 cm) and 7.6 kg (±0.2 cm), respectively. PGG are landed and gutted in Pueblo Nuevo, and therefore no information on food habits or reproduction could be gathered at this landing site. Only 6% of the landed PGG were >110 cm TL, the size at sexual maturity reported for *E. itajara* by Bullock, Murphy, Godcharles, and Mitchell (1992). These patterns were consistent throughout the years of monitoring (Figure 5). For 1428 of the landed

TABLE 1 Semi-structured interviews designed to gather traditional ecological knowledge (TEK) from fishers at the five study sites (Bahía Malaga, Jurubirá, Arusí, Bahía Solano, and Bazán)

General topics	Specific questions
General information	Name, age How many years of fishing experience do you have? How did you start fishing? Who taught you? What kind of fishing do you normally practice? Which are your most common target species?
Goliath grouper fishing	What kind of fishing technique do you know is appropriate/effective to fish goliath groupers? What fishing technique do you use? What other techniques have you observed from other fishers? What season or specific conditions are good to fish goliath groupers? What has been the largest goliath grouper that you have fished or seen? Is it possible to capture goliath groupers throughout the year? In which areas? Are these areas always the same? What is the cost of a goliath grouper fishing trip? It is profitable to fish goliath groupers? How many kinds of goliath groupers do you know?
Goliath grouper's biology	Have you observed or captured goliath groupers with eggs? In what season? What size were these goliath groupers? Is it possible to differentiate between a male and a female in goliath groupers? In which manner? Do you know what an adult goliath grouper eats? A juvenile? Do you know if goliath groupers produce any kind of sound? Have you heard this? Do you know where juvenile and adult goliath groupers occur? Are goliath groupers aggressive? Are they aggressive in a specific season? Have you captured or seen several goliath groupers at the same place and the same time? When? Where? What size?
Goliath grouper perceptions	Do you perceive that there were more goliath groupers in the past when you started fishing? How would you compare their current abundance with that of some years ago?) Do you think that goliath groupers face any threat? What do you think negatively affects or will affect the survival of goliath groupers? Do you think goliath groupers are important in the ecosystem? Do you know what role they play where they live?
Socio-economic aspects	What is the price of goliath grouper meat? To whom do you sell it? Do you eat it? What other parts of the goliath grouper do you eat or use? Are there any beliefs or myths around the goliath grouper? Is there any other name given to the goliath grouper within your locality?

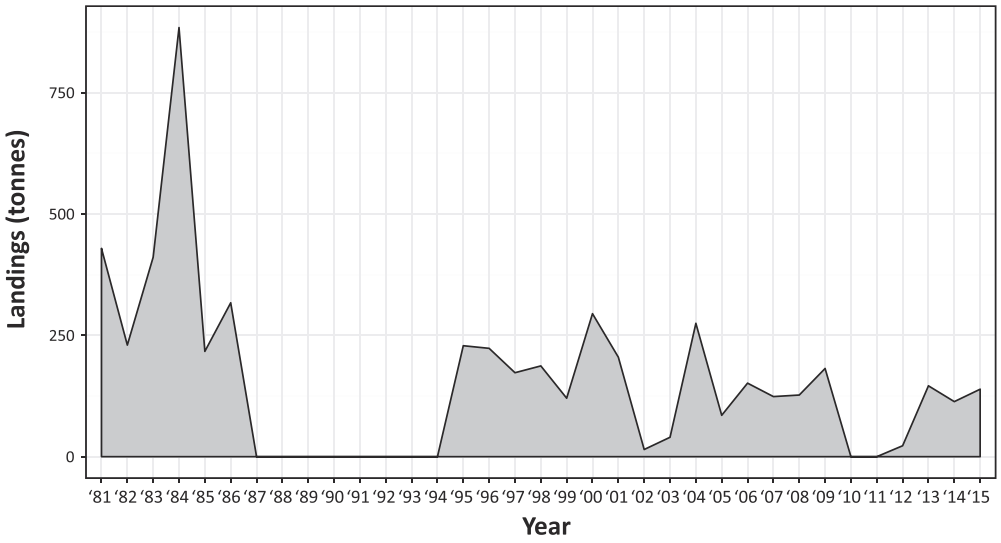

FIGURE 3 Fish landings of groupers (Epinephelidae) in the Colombian Pacific, as reported by fisheries authorities from 1981 to 2015. Data from 1981–1986 are taken from Pereira-Velásquez (1993). Data from 1995–2010 are taken from Instituto Nacional de Pesca y Acuicultura (INPA), Instituto Colombiano de Desarrollo Rural (INCODER) and Corporación Colombia Internacional (CCI) official statistics. Data from 2012–2015 are from Servicio Estadístico Pesquero Colombiano (SEPEC; http://sepec.aunap.gov.co)

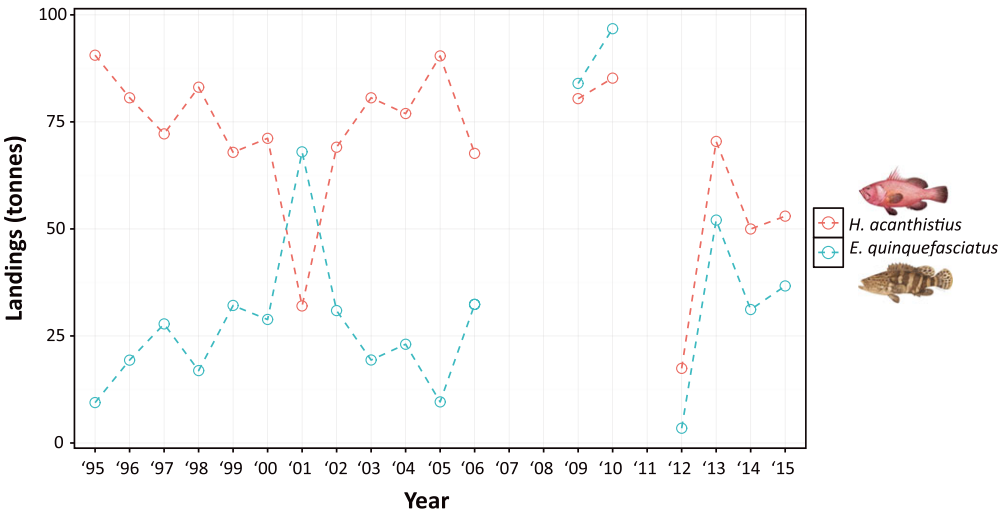

FIGURE 4 Reconstruction of landings of the two most important grouper species in the Colombian Pacific coast from 1995 to 2015 (*Hyporthodus acanthistius* and *Epinephelus quinquefasciatus*), as reported by the official statistics. Missing data from 2007–2009 indicate that statistics were not differentiated by species, whereas no official statistics are available for the 2011–2012 period

specimens it was possible to identify the fishing ground: 60% came from the southern area of Sanquianga, whereas 25% came from Juanchaco on the central Colombian Pacific coast. The remaining three fishing grounds contributed less than 10% of the total landed PGG (Figure 6). The distribution of size classes for most fishing grounds was largely represented by individuals of 50–100 cm TL. The exception to this pattern was in Juanchaco, where specimens larger than 100 cm TL were more common.

3.3 | Fishers' traditional ecological knowledge

Forty-six interviews (83% handline fishers, *n* = 38; 17% spear fishers, *n* = 8) were conducted at different small villages on the Colombian Pacific coast between 2010 and 2015. The fishing experience of the interviewees varied: 20–30 years (9%), 31–40 years (22%), 41–50 years (28%), and >50 years (41%). PGG are captured all year round; however, the interviewees identified two distinct times of the year when landings were higher – August and May. Fishers generally agreed that the better fishing in May was associated with the migration of the Pacific anchoveta (*Cetengraulis mysticetus*), which apparently causes its predator, the PGG, to be more readily caught. Irrespective of the season, 63% of fishers agreed that the best time to catch PGG is during the 3 days around the peak of spring tides (locally referred to as 'puja'). Fishers argued that the PGG only feeds during this portion of the tidal/lunar cycle.

3.3.1 | Knowledge of the biology and ecology of PGG

Seventy-two percent of those interviewed could not identify any sexual dimorphism in PGG, although 26% described females as shorter and

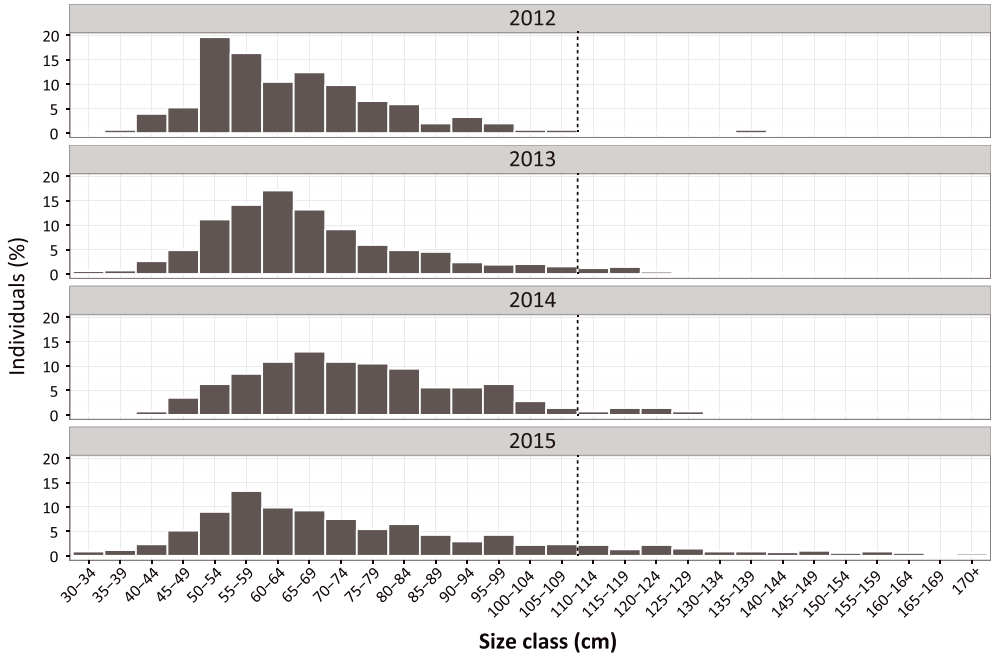

FIGURE 5 Size structure of goliath groupers landed (n = 1981) from 2012 to 2015 at the principal landing sites in Buenaventura, on the Colombian Pacific coast, tropical Eastern Pacific. Dashed lines indicate the approximate size at which ontogenetic shifts occur in goliath groupers in the Atlantic Ocean (juveniles to adults; ~100 cm TL) according to Frias-Torres (2006) and Koenig et al. (2007)

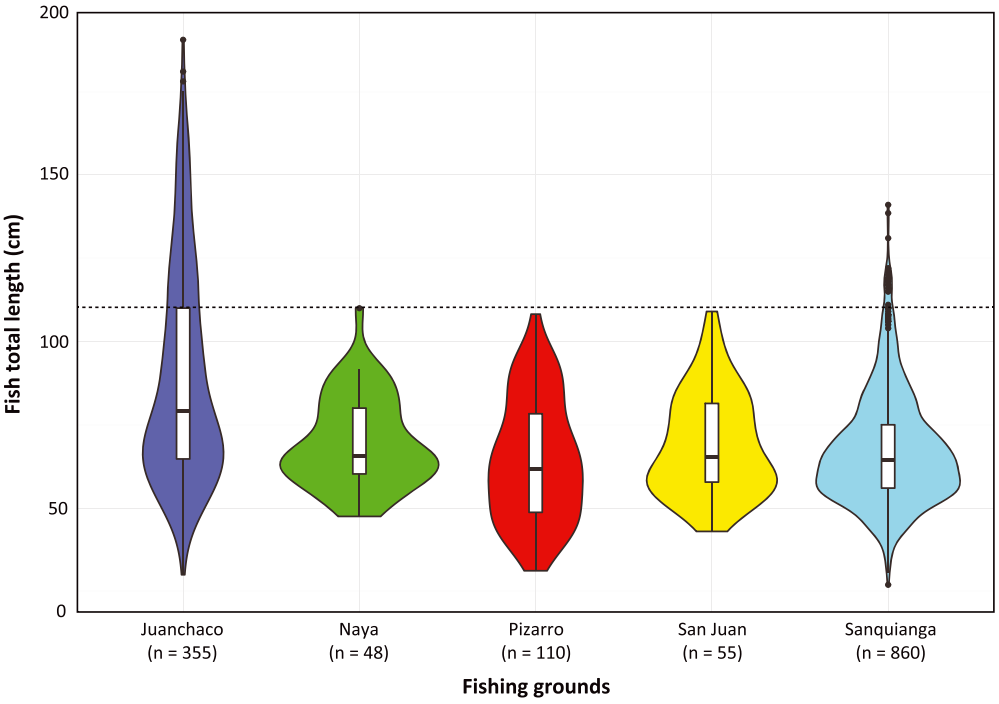

FIGURE 6 Violin plot indicating the median sizes of goliath groupers caught in different regions along the Colombian Pacific coast (see Figure 2). The plot also shows the size distribution of individuals between fishing grounds. The dashed lines indicates the approximate size at which ontogenetic shifts occur in goliath groupers in the Atlantic Ocean (juveniles to adults; ~100 cm TL) according to Frias-Torres (2006) and Koenig et al. (2007)

'fatter' and males as more elongated. Forty-six percent of the interviewees had never seen mature females of PGG, whereas 43% had only observed eggs once or rarely. The reproductive season and length at maturity is therefore unclear. Handline fishers identified black skipjack (patiseca, *Euthynnus lineatus*) as the preferred food of the PGG, and this was the fish species most commonly used as bait (52%).

The emission of loud, abrupt, and low-frequency sounds by PGG was acknowledged by 76% of the informants. The most experienced fishers could use the unique sound made by the PGG to determine the approximate location of the fish.

Most fishers agreed that 'juvenile' PGG prefer to live in shallow estuarine habitats with high structural complexity (e.g. mangrove roots,

logfalls), whereas 'adults' prefer to live in or near shallow (<30 m) offshore rocky reefs of high complexity (caves, rocky reefs, wrecks, etc.). Eighty-five percent of those interviewed agreed that PGG experience an ontogenetic habitat shift from estuarine to offshore habitats, which is consistent with that of the Atlantic goliath grouper. PGG behaviour in general was described as passive (61%), although spearfishers described aggressive behaviour after a failed shot, with the fish swimming towards them in self-defence or to attack. During one such incident, one spearfisher interviewed reported being half-swallowed headfirst and released, an account corroborated by several other local fishers.

3.3.2 | Perceptions on PGG conservation

Most fishers (89%) agreed that there has been a decline in the local PGG population over time. This decline is mainly attributed to increased fishing effort (with an increasing number of fishers in the area) and newly introduced spearfishing methods; however, 9% of the interviewees (all of them spearfishers) agreed that there have not been any changes in the population size, and that they have witnessed recent large aggregations (>20 individuals) of adult PGG near Cabo Corrientes and Cabo Marzo on the northern rocky coast of the Colombian Pacific (Figure 1). Despite the perception of declines in the PGG population, the overall fisher responses showed no clear indications of declines in the size at catch or in the number of fish caught to suggest a shifting baseline syndrome situation.

3.3.3 | Socio-economics of PGG fisheries

In the northern area of Cabo Corrientes PGG is sold on average for US $2 per kilo (gutted fish), no matter the size of the fish. In the southern part (Bahía Málaga and Guapi) of the study area, which is closest to the main market (Buenaventura), PGG weighing between 2.5 and 25.0 kg (i.e. smaller immature individuals) fetch a better market price (US $3.7 per kilo) than individuals that weigh >25 kg (US $1.8 per kilo). Fishers normally associate larger PGG individuals with tougher flesh. For most fishers, PGG are not a targeted resource, but are rather occasionally and opportunistically caught, which is reflected in the low market prices compared with other more valuable species (e.g. snappers).

4 | DISCUSSION

An active Pacific goliath grouper fishery in the tropical Eastern Pacific has not previously been reported upon. Findings indicate that the PGG has increased its representation in overall grouper landings on the Colombian Pacific coast over the last 15 years. The fishery for PGG is currently as important in catches as that for the rooster hind, which has been historically the most important targeted grouper species in the region. Although the TEK from fishers does not indicate serious declines in PGG populations, an increasing fishing effort on immature fish could eventually lead to growth overfishing, and represents a warning signal to regulate fisheries for this species. Equally worrying is the apparent increase in spearfishing in some regions of the Colombian Pacific (e.g. northern and central coasts). Spearfishers normally target large and old PGG (Figure 1). Targeting this part of the stock is increasingly recognized for generating size and age truncation (Hixon, Johnson, & Sogard, 2014), which in turn reduces the productivity and stability of marine communities (Barnett, Branch, Ranasinghe, & Essington, 2017).

Grouper fisheries in the Colombian Pacific coast have been formally documented since the 1980s by fishing authorities, although several species of this group have been traditionally harvested by small-scale fishers prior to 1980. Landing values of ~400 tons per year at the beginning of that decade contrast with the current landing values of below 200 tons per year. This apparent decline should be interpreted with caution as official landing statistics have been irregularly collected throughout the years; however, if it is assumed that the accessibility to landing sites and data gathering has increased over the years, the decline in landings suggests a declining PGG fishery.

In the 1990s, a semi-industrial fleet targeting four different grouper species in the Colombian Pacific was active (Gómez & Zapata, 1999). Olive grouper (*Epinephelus cifuentesi*) and rooster hind were the target species of this fleet, whereas PGG were poorly represented in catches. Since 2000, after an apparent collapse of this semi-industrial fishery, most grouper landings in the Colombian Pacific comprise rooster hind and PGG (Figure 4). PGG landings in the Colombian Pacific remained relatively constant between 1995 and 2006, with landings usually not exceeding 50 tons per year (except for the years 2000 and 2001). These catch values are around 10 times lower than those reported for the Atlantic goliath grouper on the entire Brazilian coast (393 ton per year; Giglio, Bertoncini, Ferreira, Hostim-Silva, & Freitas, 2014), where this species is protected from fishing by law but the enforcement seems to be weak (Giglio et al., 2014). It is likely, however, that the PGG landing values for the Pacific Colombian coasts are the highest of all countries in the Eastern Pacific where PGG is distributed.

The increase in PGG landings (up to 80 tons per year) in 2009 and 2010 may be indicative of a greater fishing effort on this species. This increase is potentially driven by the demand of the national market, especially in the largest cities of the country (Cali, Bogotá, and Medellín), and even on the Caribbean coast of Colombia where there is a demand for grouper fillet from the tourism sector. Of special concern is the fact that fish retailers prefer small, immature PGG, which fetch considerably higher prices in the market. This is in contrast to what was found in Belize by Graham et al. (2009), where larger groupers provide greater income to fishers.

Information provided by the TEK of fishers helps to fill in some knowledge gaps about basic PGG biological aspects, and provides insights into the perceived long-term trends in catches and abundances of the PGG, especially in the northern area of the Colombian Pacific coast. Similarities in the biological characteristics of the PGG and the Atlantic goliath grouper (Aguilar-Perera, González-Salas, Tuz-Sulub, & Villegas-Hernández, 2009; Frias-Torres, 2006), such as ontogenic habitat shifts and sound production, were observed. Interestingly, most fishers were not aware of the reproductive cycle of PGG.

On the northern Colombian Pacific coast, the PGG fishery has been discouraged by non-governmental organizations (NGOs) claiming that the PGG is currently at risk of extinction, although apparently this is caused by confusion with the conservation status of the Atlantic goliath grouper (*Epinephelus itajara*). This has decreased the overall fishing pressure on this resource in this region; however, at the southern coast's main landing port of Buenaventura, the PGG is currently actively

landed, although not targeted, as fishers tended to pursue other species that are more readily caught and command better prices.

The prevailing environmental and socio-economic conditions in the Colombian Pacific region (e.g. highest rainfall in the Americas), high mangrove densities, and low human population densities, may have all combined to mitigate against severe population declines in PGG in Colombia. The Colombian Pacific is sparsely populated (with five inhabitants per km^2; Meisel Roca & Pérez V, 2006), and therefore fishing pressure is thought to be low compared with other coastal regions in the tropical Eastern Pacific.

Although PGG exploitation along the Pacific coast of Colombia and its effects on the populations appear to be not as severe as those observed in other areas of the region (i.e. the Gulf of California; Aburto-Oropeza, Erisman, Valdez-Ornelas, & Danemann, 2008), the current signs of increased exploitation, higher demand from the local market (especially of juvenile individuals), and introduction of fishing gear that target large individuals (i.e. spearfishing), are warning signals for the future of this species in Colombia, and indicate that conservation action is a priority. The Colombian Government's planned developments along the Pacific coast (e.g. new harbours and roads that lead to human population increase and loss of critical habitat) in the near future are likely to increase the pressure on fishery resources and vulnerable species such as the PGG.

Implementing realistic conservation and management measures is not an easy task in countries like Colombia, where fisheries are not priorities for central governments. Nevertheless, measures that protect or limit the catch of juvenile and very old fish could greatly improve the sustainability of the PGG fishery (Kindsvater, Reynolds, Sadovy de Mitcheson, & Mangel, 2017), it should be made clear that size limits were only recommended, but not implemented in Belize for the Atlantic goliath grouper (Graham, pers. comm. 2017). The Colombian government declared in 2017 special management areas (Distritos de Manejo Integrado) in two significant mangrove zones of the Colombian Pacific (Cabo Manglares Bajo Mira y Frontera and El Encanto de los Manglares del Bajo Baudó). This brings the opportunity to give protection to PGG individuals prior to maturity in their nursery habitats. The challenge facing these special management areas is to actually achieve their conservation and sustainability goals, and not just remain as parks on paper (see Rife, Erisman, Sanchez, & Aburto-Oropeza, 2013). It is equally important to give protection to spawning aggregation sites, which need to be identified, as they are the sites where spear fisheries are increasingly likely to operate and extract large PGG. An additional management measure would be to impose maximum and minimum size limits so that the fishery only affects a small range of ages (Barnett et al., 2017). Finally, research addressing poorly known aspects of the ecology and biology of PGG should accompany the continuing conservation and management efforts. Of special relevance are the identification of migration routes of juvenile and adult PGG, and a stock assessment, with reliable growth rate, abundance, and life-history parameters for this species.

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REFERENCES

Aburto-Oropeza, O., Erisman, B., Valdez-Ornelas, V., & Danemann, G. (2008). Commercially important serranid fishes from the Gulf of California: Ecology, fisheries, and conservation. *Ciencia y Conservación*, *2008*(1), 1–44.

Aguilar-Perera, A., González-Salas, C., Tuz-Sulub, A., & Villegas-Hernández, H. (2009). Fishery of the Goliath grouper, *Epinephelus itajara* (Teleostei: Epinephelidae) based on local ecological knowledge and fishery records in Yucatan, Mexico. *Revista de Biología Tropical*, *57*(3), 557–566.

Baos, R., Castellanos-Galindo, G. A., Chong-Montenegro, C., Tompkins, P., & Zapata, L. A. (2016). Length–weight relationship of the Pacific goliath grouper, *Epinephelus quinquefasciatus* (Bocourt, 1868). *Journal of Applied Ichthyology*, *32*(4), 727–728.

Barnett, L. A. K., Branch, T. A., Ranasinghe, R. A., & Essington, T. E. (2017). Old-Growth Fishes Become Scarce under Fishing. *Current Biology*, *27*(18), 2843–2848.

Beaudreau, A. H., & Levin, P. S. (2014). Advancing the use of local ecological knowledge for assessing data-poor species in coastal ecosystems. *Ecological Applications*, *24*(2), 244–256.

Bullock, L. H., Murphy, M. D., Godcharles, M. F., & Mitchell, M. E. (1992). Age, growth, and reproduction of jewfish *Epinephelus itajara* in the eastern Gulf of Mexico. *Fishery Bulletin*, *90*(2), 243–249.

Castellanos-Galindo, G. A., Cantera, J., Saint-Paul, U., & Ferrol-Schulte, D. (2015). Threats to mangrove social-ecological systems in the most luxuriant coastal forests of the Neotropics. *Biodiversity and Conservation*, *24*(3), 701–704.

Castellanos-Galindo, G. A., Baos, R., & Zapata, L. A. (2017). *Epinephelus quinquefasciatus*. In L. V. Chasqui, F. A. Polanco, P. A. Acero, P. A. Mejía-Falla, A. Navia, L. A. Zapata, & J. P. Caldas (Eds.), *Libro rojo de peces marinos de Colombia* (pp. 432–436). Santa Marta, Colombia: Instituto de Investigaciones Marinas y Costeras INVEMAR, Ministerio de Ambiente y Desarrollo Sostenible.

Correa, I., & Morton, R. (2010). Pacific coast of Colombia. In E. C. F. Bird (Ed.), *Encyclopedia of the world's coastal landforms* (pp. 193–197). Dordrecht, the Netherlands: Springer.

Craig, M. T., Graham, R. T., Torres, R. A., Hyde, J. R., Freitas, M. O., Ferreira, B. P., … Robertson, D. R. (2009). How many species of Goliath Grouper are there? Cryptic genetic divergence in a threatened marine species and the resurrection of a geopolitical species. *Endangered Species Research*, *7*(3), 167–174.

Craig, M. T., Sadovy de Mitcheson, Y. J., & Heemstra, P. C. (2011). *Groupers of the World: A Field and Market Guide*. Grahamstown, South Africa: NISC (Pty) Ltd.

Erisman, B. (2011). *Epinephelus quinquefasciatus*. In IUCN Red List of Threatened Species v2011.2. Available at http://www.iucnredlist.org. Accessed on 29 May 2017.

Frias-Torres, S. (2006). Habitat use of juvenile goliath grouper *Epinephelus itajara* in the Florida Keys, USA. *Endangered Species Research*, *2*, 1–6.

Gaspari, L., Bryceson, I., & Kulindwa, K. (2015). Complementarity of fishers' traditional ecological knowledge and conventional science:

Contributions to the management of groupers (Epinephelinae) fisheries around Mafia Island, Tanzania. *Ocean & Coastal Management*, *114*, 88–101.

Gerhardinger, L. C., Marenzi, R. C., Bertoncini, A. A., Medeiros, R. P., & Hostim-Silva, M. (2006). Local Ecological Knowledge on the Goliath Grouper *Epinephelus itajara* (Teleostei: Serranidae) in Sourthern Brazil. *Neotropical Ichthyology*, *4*(4), 441–450.

Giglio, V. J., Bertoncini, Á. A., Ferreira, B. P., Hostim-Silva, M., & Freitas, M. O. (2014). Landings of goliath grouper, *Epinephelus itajara*, in Brazil: despite prohibited over ten years, fishing continues. *Natureza & Conservação*, *12*(2), 118–123.

Glynn, P. W., & Ault, J. S. (2000). A biogeographic analysis and review of the far eastern Pacific coral reef region. *Coral Reefs*, *19*(1), 1–23.

Gómez, A. E., & Zapata, L. A. (1999). Generalidades sobre la pesquería y biología de las chernas y meros (Pisces: Serranidae) en el Pacífico colombiano. *Boletín Científico INPA*, *6*(1), 227–246.

Graham, R. T., Rhodes, K. L., & Castellanos, D. (2009). Characterization of the Goliath Grouper *Epinephelus itajara* fishery of southern Belize for conservation planning. *Endangered Species Research*, *7*, 195–204.

Heemstra, P. C., & Randall, J. E. (1993). *Groupers of the World* (Vol. 16). Rome, Italy: FAO Species Catalog.

Heyman, W. D., & Graham, R. T. (2000a). *The Voice of the Fishermen of Southern Belize*. Punta Gorda, Belize: Toledo Institute for Development and Environment (TIDE) & Trinational Alliance for the Gulf of Honduras (TRIGOH).

Heyman, W. D., & Graham, R. T. (2000b). *La Voz de los Pescadores de la Costa Atlántica de Honduras*. Tela, Honduras: Prolansate.

Heyman, W. D., & Graham, R. T. (2000c). *La Voz de los Pescadores de la Costa Atlántica de Guatemala*. Ciudad de Guatemala, Guatemala: FUNDAECO.

Hind, E. J. (2015). A review of the past, the present, and the future of fishers' knowledge research: A challenge to established fisheries science. *ICES Journal of Marine Sciences*, *72*(2), 341–358.

Hixon, M. A., & Carr, M. H. (1997). Synergistic predation, density dependence, and population regulation in marine fish. *Science*, *277*(5328), 946–949.

Hixon, M. A., Johnson, D. W., & Sogard, S. M. (2014). BOFFFFs: On the importance of conserving old-growth age structure in fishery populations. *ICES Journal of Marine Science*, *71*(8), 2171–2185.

Johannes, R. E. (1998). The case of data-less marine resource management: examples from tropical nearshore fin fisheries. *Trends in Ecology and Evolution*, *13*(6), 243–246.

Kindsvater, H. K., Reynolds, J. D., Sadovy de Mitcheson, Y., & Mangel, M. (2017). Selectivity matters: Rules of thumb for management of plate-sized, sex-changing fish in the live reef food fish trade. *Fish and Fisheries*, *18*(5), 821–836.

Koenig, C. C., Coleman, F. C., Eklund, A. M., Schull, J., & Ueland, J. (2007). Mangroves as essential nursery habitat for goliath grouper (*Epinephelus itajara*). *Bulletin of Marine Science*, *80*(3), 567–586.

MADR (Ministerio de Agricultura y Desarrollo Rural) & CCI (Corporación Colombia Internacional). (2011). *Pesca y Acuicultura Colombia 2010*. Bogotá, Columbia: Corporación Colombia Internacional.

Meisel Roca, A., & Pérez V, G. J. (2006). Geografía física y poblamiento en la costa Caribe Colombiana. *Documentos de trabajo sobre economía regional*, *73*, 1–79.

Mejía, L., & Acero, A. (2002). *Libro rojo de peces marinos de Colombia. La serie Libros Rojos de Especies Amenazadas de Colombia*. Bogotá, Colombia: INVEMAR, Instituto de Ciencias Naturales – Universidad Nacional de Colombia, and Ministerio del Medio Ambiente.

Pereira-Velásquez, F. (1993). La pesca en el Pacífico. In P. Leyva (Ed.), *Colombia, Pacífico, Tomo II. Proyecto Biopacífico*. Santa Fe de Bogotá, Colombia: Fondo para la Protección del Medio Ambiente, FEN.

Polidoro, B. A., Brooks, T., Carpenter, K. E., Edgar, G. J., Henderson, S., Sanciangco, J., & Robertson, D. R. (2012). Patterns of extinction risk and threat for marine vertebrates and habitat-forming species in the Tropical Eastern Pacific. *Marine Ecology Progress Series*, *448*, 93–104.

Poveda, G., & Mesa, O. J. (2000). On the existence of Lloró (the rainiest locality on Earth): Enhanced ocean-land-atmosphere interaction by a low-level jet. *Geophysical Research Letters*, *27*(11), 1675–1678.

Ramírez, J. J. C., & de Aguas, P.,. J. M. (2015). *Escalafón de la competitividad de los departamentos de Colombia 2015*. Santiago de Chile, Chile: CEPAL Naciones Unidas.

Rife, A. N., Erisman, B., Sanchez, A., & Aburto-Oropeza, O. (2013). When good intentions are not enough … Insights on networks of "paper park" marine protected areas. *Conservation Letters*, *6*(3), 200–212.

Sadovy, Y., & Eklund, A. (1999). Synopsis of Biological Data on the Nassau Grouper, *Ephinephelus striatus*, and the Jewfish, *E. itajara*. NOAA Technical Report. Seattle, Washington, USA: University of California Libraries.

Sadovy de Mitcheson, I., Craig, M. T., Bertoncini, A. A., Carpenter, K. E., Cheung, W. W. L., Choat, J. H., … Sanciangco, J. (2013). Fishing groupers towards extinction: A global assessment on threats and extinction risks in a billion dollar fishery. *Fish and Fisheries*, *14*(2), 119–133.

Sáenz-Arroyo, A., Roberts, C. M., Torre, J., Cariño-Olvera, M., & Enriquez-Andrade, R. R. (2005). Rapidly shifting environmental baselines among fishers of the Gulf of California. *Proceedings of the Royal Society of London B*, *272*(1575), 1957–1962.

Stewart, B. D., & Jones, G. P. (2001). Associations between the abundance of piscivorous fishes and their prey on coral reefs: Implications for prey-fish mortality. *Marine Biology*, *138*(2), 383–397.

Wielgus, J., Zeller, D., Caicedo-Herrera, D., & Sumaila, R. (2010). Estimation of fisheries removals and primary economic impact of the small-scale and industrial marine fisheries in Colombia. *Marine Policy*, *34*(3), 506–513.

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