Title: Diving into archival data: the hidden decline of the giant grouper (*Epinephelus lanceolatus*) in Queensland, Australia

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Abstract

The giant grouper (*Epinephelus lanceolatus*) is the largest reef fish in the Indo-Pacific (~ 2.5 m TL, > 400 kg), and it is highly susceptible to overfishing. Despite regional protections and documented population declines, the species is listed by IUCN as Data Deficient due to minimal long-term population data and a paucity of life history information. This study used historical fishing records derived from newspaper articles, fishing magazines, grey literature, and naturalists' descriptions to collate life history information and reconstruct giant grouper population trends from 1854 to 1958 in Queensland, Australia. Historical recreational catch trends of four biologically distinct grouper size classes demonstrated that over 92 years, fishing disproportionately affected two size classes: immature (fish below reproductive size), and mature individuals. Changes in the probability of capturing a grouper within a recreational fishery were examined as a proxy of relative abundance. The probability of catching a giant grouper within a popular recreational fishery significantly declined from 81% in 1860 to 2% in 1958. Further analysis based on a nonprobabilistic method of giant grouper sighting records, showed fluctuations in the giant grouper population trajectory, from a steady decline during the early 20th century, to an increase during WWII (1939-1945) followed by a reduction in the last half of the

20th century. This study highlights the importance of archival sources to uncover population trends of rare species by combining quantitative assessments and biological inferences to determine the timing and occurrence of population declines and recoveries and inform how vulnerable fish species respond to the cumulative effects of fishing over time.

Keywords:
Historical ecology, conservation, fisheries, extinction risk, data-limited, time-series

1. Introduction

Over the past century, unprecedented levels of anthropogenic impacts on the environment have led to a significant loss of biological diversity at rates comparable to previous mass extinctions (Piperno, 2007, Malhi et al., 2016). In the marine environment, fish populations globally have experienced a 38% decline in abundance (McCauley et al., 2015). These population declines have been concurrent with the rapid industrialization of fishing and expanding fishing effort across large geographical areas (Tickler et al., 2018). Historically, overfishing has been characterized by targeting and overexploiting large marine animals that usually occupy high trophic levels (Jackson et al., 2001). The extensive removal of these large predatory fish can have significant impacts on complex ecosystems, such as alteration of trophic structures, declines in species diversity, and reduction in the species' geographical ranges (Estes et al., 2011, Maxwell et al., 2013, Price et al., 2019). Consequently, severe overfishing can lead to local and functional extinctions (Jackson et al., 2001). That is, while exploited marine species might be extant at low abundances, they are unable to significantly interact with other species in the community and perform their ecological role (Dirzo et al., 2014, McCauley et al., 2015).

Groupers (Epinephelidae) are large-bodied marine fish heavily exploited by the commercial (Sadovy de Mitcheson et al., 2020), recreational and subsistence fishing sectors (McClenachan, 2009b, Giglio et al., 2017), that also play significant roles as top predators in coastal ecosystems (Stallings, 2008). Species within this family exhibit life history characteristics that make them susceptible to overfishing; they are long-lived species (decades), have slow growth rates, late maturity, have complex reproductive strategies (e.g., protogynous hermaphrodite [female-first]), and often form predictable spawning aggregations (Sadovy & Colin, 1995, Sadovy de Mitcheson et al., 2013). Severe population declines in response to fishing pressure have been documented for numerous grouper species, including the Nassau grouper (*Epinephelus striatus*) in several regions across the Caribbean (Belize; Sala et al. (2001), and the Yucatan Peninsula, Mexico; Alfonso (2006)), the Gulf Grouper in northwest Mexico (Sáenz–Arroyo et al., 2005), and the Atlantic goliath grouper (*Epinephelus itajara*) across its range (Florida, USA, McClenachan (2009b), McClenachan (2009a); Brazil, Giglio et al. (2017)). With continuing global market demand for groupers and the increasing concern of population decline (Sadovy de Mitcheson et al., 2020), the International Union for Conservation of Nature (IUCN Standards and Petitions Committee) in 1998, established a specialist group of scientists to assess the extinction risk of all grouper species.

Extinction risk assessments (e.g., sighting frequency, population projections) can ensure the future conservation of the species (e.g., conservation effectiveness) by guiding informed decision-making strategies regarding policies and allocation of monetary resources toward the conservation of species at risk (Cheung et al., 2005, Boakes et al., 2015). However, for most severely depleted or rare species, quantitative information about past abundances, distributions, habitat preferences, and life history traits are scarce, limiting assessments of species' population status (Bland et al., 2017). For example, of the 168 grouper species, 30% are considered 'Data Deficient (DD)' by the IUCN due to insufficient biological and fisheries data to determine their risk status (Sadovy de Mitcheson et al., 2013). Lack of informative data can potentially mask the true risk category of the species, and it has been argued that species within the DD category should be treated with the same degree of protection as threatened species (Luiz et al., 2016, Bland et al., 2017).

The giant grouper (*Epinephelus lanceolatus*) is one of the four species of grouper (i.e., *E. itajara, E quinquefasciatus, Hyporthodus nigritus*) that can weigh up to 400 kg and exceed total lengths of two meters (Craig et al., 2011). Despite the giant grouper being the most widely distributed grouper species throughout the Indo-Pacific, this species occurs in low abundance even on unexploited grounds (Fennessy et al., 2008). Rare species are often more vulnerable to anthropogenic disturbances and environmental disturbances, such as overexploitation and environmental stochasticity, than common species (Harnik et al., 2012, Leitão et al., 2016). For example, overfishing has been documented as the primary cause of localized depletions of the giant grouper across its distribution (Fennessy et al., 2008). Despite this evidence of population declines, the IUCN recognizes this species as 'Data Deficient' due to insufficient long-term quantitative data and life history information to establish its risk status (Fennessy et al., 2008). In Australia, the giant grouper has been categorized as a protected species since 1994 [*Fisheries Management Act 1994*], with no-take regulations in several states and territories (i.e., Western Australia, Northern Territory, New South Wales, and Queensland). Despite conservation efforts for the species, there is little quantitative information on historical population trends and life history characteristics from wild populations that can help inform the conservation status of the species (Fennessy et al., 2008).

Within the field of marine historical ecology, interdisciplinary approaches have been developed to reveal information about past species' population trajectories and inform about the cumulative anthropogenic impacts of fishing on marine species (Drew et al., 2016, Early‐Capistrán et al., 2018, Miller et al., 2019). Past population trends and species distributions have been reconstructed from historical records, naturalists' species lists, and local catch reports (Thurstan et al., 2018, Chong-Montenegro et al., 2022a). The application of quantitative approaches to analyze archival data, such as estimates of relative abundance of rare species (e.g., species represented in low proportions in the catch) have been used to reveal underlying population trends (Kerwath et al., 2019). In addition, sighting records have helped assess populations' trajectories, providing valuable information about the magnitude of declines that populations have suffered in the past (McPherson & Myers, 2009, Moro et al., 2020) and helped to reveal the effectiveness of conservation strategies (Luiz & Edwards, 2011).

Given the scarcity of fisheries dependent and independent data for the giant grouper, this work used fishing records derived from newspaper articles, fishing magazines, and naturalists' descriptions to describe the historical fisheries context, derive biological information for this data deficient species, and assess its population trends in Queensland, Australia. More specifically, this study sought to i) evaluate trends in reported catches in terms of weight (kg) and size (cm) of the giant grouper caught through time, ii) assess changes in the probability of capture based on fishing reports, iii) evaluate the population trajectory, and iv) document life history characteristics, such as habitat preferences, species behaviors, feeding habits and reproduction. This research highlights the importance of using archival sources to inform past exploitation, population trajectories and biological data for a Data Deficient species.

The authors acknowledge the Aboriginal peoples of Queensland and the long history of fishing practices along the east coast of Queensland. We note that no written records specific to Indigenous fishing were found in the sampled sources, and therefore Aboriginal fishing catches for the giant grouper were not included in this study.

2. Methods

2.1 Data collection

An online digital repository (TROVE) of major Australian newspapers from 1803 to 1958 was used to source quantitative fisheries data and biological descriptions of the giant grouper (NLA, 2019). Prior to the online systematic data search, two popular fishing books about Queensland fish and fisheries published in the early 20th century were referenced to validate the most common name given to the giant grouper (Welsby, 1905, Ogilby, 1915). Ogilby (1915) provided a list of ichthyological information about species within the Serranidae family and the common names used at the time (e.g., "We now come to the great Queensland '*groper'* (*Promicrops lanceolata*), probably the largest teleost now in existence except the swordfishes", Ogilby (1915)). Following the confirmation of the common name for *E. lanceolatus*, a systematic online search was conducted using the following combination of keywords: "groper" AND "fish" AND "fishing", and filtered to newspapers from Queensland only. For consistency, throughout the manuscript, '*groper*' is referred to as giant grouper as it is the globally recognized species' common name.

To expand the temporal cover of newspaper articles, additional newspapers were manually sourced from the Queensland State Library Archives. Due to the large number of newspaper editions per year and across the state of Queensland, a total of 505 newspaper articles (i.e., *Brisbane Telegraph*, *The Daily Mail*, and *Daily Standard*) were reviewed spanning even years from 1960 to 1980 (>1959, n = 505), and limited to the Brisbane area only.

To further expand the temporal extent of the data, additional sources such as naturalists' books, and fishing magazines were manually searched from archives at the Queensland State Library. Available fishing magazines from the library were limited in quantity and quality. There were only four magazines available from archives, with sporadic numbers of editions per year: *Fish and Boat* (years reviewed (YR): 1988-1994), *The Queensland Fisherman* (YR: 1986, 1988, 1990, 1992), *Bush n Beach* (YR: 1991, 1994, 1996), and *Queensland fishing monthly* (YR: 1992). The number of volumes (i.e., individual numbers of magazines) available per year varied among fishing magazines (*Queensland fishing monthly,* n = 11; *Fish and Boat*, n = 74; *Bush n Beach*, n = 3; The Queensland Fisherman, n = 23). Across all magazines, a total of 133 volumes were reviewed.

In addition, two naturalist books by marine biologist William Saville-Kent (1845-1908) were sourced for biological information (i.e., The Great Barrier Reef of Australia; Its Products and Potentialities (1893), The Naturalist in Australia (1897)). Lastly, the results of the '*Fishing Experiments Carried Out by the F.I.S Endeavour'* (1909) for Queensland were also reviewed. The *F.I.S Endeavour* was a research vessel sent by the Commonwealth Government (1907) to investigate suitable fishing grounds across Australia.

For each sampled data, information on *year, size of the grouper caught, total length, location fished,* and narratives associated with the giant grouper were collated. From these narratives, qualitative descriptors about *habitat preferences*, *species behaviors*, *feeding habits* and *reproduction* were derived when available.

2.2 Catch trends

Two approaches were used to assess catch trends of the giant grouper population over time.

First, a generalized linear model (GLM) was fitted to test for significant changes in the mean giant grouper weight (kg) reported over time. The model was fitted with a normal distribution and a logarithmic link function using the glm function from the stats R package (R Core Team, 2022). Model validation was conducted by plotting the residuals against the predicted values and assessing the homogeneity of variance and normality of distribution using the performance package in R (Lüdecke et al., 2020).

Second, four separate logistic regressions were fitted to the presence or absence of four biologically distinct grouper size classes to assess changes in the probability of reporting a size class over time. Given that length data are the most commonly used metric in fisheries management, and is often used to assess the status of populations (Maunder & Punt, 2013), grouper weight data were transformed into total length using the weight-length relationship equation ($W = aL^b$; where $a = 0.01175, b = 2.88$) (Froese & Pauly, 2010). The transformed data were grouped into four size categories based on Froese (2004) framework: 1) immature fish (defined as fish below size at first maturity); 2) mature fish (L_m), 2) fish within an optimum length (L_{opt}) (defined as the length of fish where maximum yield is achieved), and 4) mega-spawners (Froese, 2004).

Each indicator was estimated as follows: 1) immature fish below 110 cm TL, 2) size at first maturity (L_m) was set at a range of 110-130 cm TL (Bullock et al., 1992); 2) optimum length (L_{opt}) of catch was estimated using the following equation: $L_{opt=}10^{1.0421*\log(L_\infty)-0.27422}$ (Froese & Binohlan, 2000) where $L_\infty = 192$, represents the asymptotic length (cm) in the von Bertalanffy growth function (Artero et al., 2015). Thus, the optimal length interval was calculated as $182\ cm \pm$10% of L_{opt}; and 4) mega-spawners were estimated as fish above >= 200 cm ($L_{opt} + 10\%$). Given that the giant grouper might follow a sex-change reproductive strategy, we assume that both un-transitioned females (i.e., big old fat fecund females [BOFFF]) and large males (few but large individuals) are part of this category and are considered significant contributors to the overall reproductive population (Hixon et al., 2013).

Life history parameters for the giant grouper were inferred from a closely related and well-studied grouper species, the Atlantic goliath grouper (*Epinephelus itajara*). In terms of reproductive strategy, in this work, we assumed that *E. lanceolatus* follows a diandric protogynous hermaphroditism strategy (Palma et al., 2019).

2.3 Probability of capture

Changes in the relative abundance of two co-existing and recreationally exploited species, the giant grouper and snapper (*Pagrus auratus*), were explored as a proxy to evaluate the effects of fishing (i.e., catching one or both species) in a given fishery (Kerwath et al., 2019). Three probability estimates were explored: i) the probability of catching grouper in a snapper outing (i.e., $\Psi^{Gr} = P(Gr|Sn)$); ii) the probability of catching snapper in a grouper outing (i.e., $\Psi^{Sn} = P(Sn|Gr)$), and iii) the probability of co-occurrence (catching grouper and snapper) in a grouper or snapper outing ($\Psi^{Gr,Sn} = P[(Gr \cap Sn) | (Gr | Sn)]$).

Snapper was chosen for joint species modelling, given that it is a species known to co-exist with giant grouper in similar habitats (i.e., rocky reefs), is a top predator, and historically has been targeted with similar fishing gear (i.e., rod, hook and line) (Welsby, 1905). In addition, snapper has been exploited by the commercial and recreational fishing sectors since the early 19th century, and these fishing activities have been extensively documented (Welsby, 1905, Thurstan et al., 2016). Lastly, snapper grows at a faster rate ($k = 0.18$) than the giant grouper ($k = 0.12$) and occurs at higher abundances, making it an ideal candidate to compare the effects of fishing on two co-existing but biologically different species (Bullock et al., 1992, Jackson et al., 2010, Leitão et al., 2016).

Total numbers of fishing trips for giant grouper and snapper were obtained from newspaper articles using standardized search terms and geographically restricting articles to Queensland only. Individual trips were defined as species-specific outings when one of the two focal species was absent from the report. For snapper-only outings, the following search terms were used to exclude grouper from the reports, “snapper” AND “schnapper” AND “fishing” NOT “groper”, and vice versa for giant grouper -only fishing trips (i.e., search terms used: “groper” AND “fishing” NOT “snapper”, NOT “schnapper”). Co-occurrence fishing trips were defined as outings when grouper and snapper were reported jointly (search term used: “snapper” AND “schnapper” AND “fishing” AND “groper”).

2.4 Population trends

Population trends from archival records of giant grouper along the east coast of Queensland were evaluated using a nonprobabilistic approach developed by McPherson & Myers (2009). This method allows for estimates of the relative magnitude of population change given count data (i.e., grouper sightings in reports) by fitting a series of generalized linear models (GLMs) to the differences in count data between any reference point and the most recent observation while providing uncertainty around the estimates. This approach assumes that observations (i.e., sightings) are independent of each other, and the probability of sighting (e.g., effort) is equal through time (McPherson & Myers, 2009). Thus, to apply this approach to the giant grouper fishery in Queensland, two assumptions were made; first, fishing effort remained consistent over time (Chong-Montenegro et al., 2022b), and second, line fishing was the primary gear used throughout the study period (Thurstan et al., 2016). All models were fitted using a Poisson error distribution with a log link function. Model validation was conducted by testing for overdispersion and inspecting the homogeneity distribution of the residuals. To determine the robustness of the models, a sensitivity analysis was applied to the models by changing the length of the time series (i.e., adjusting the reference year). Values larger than one represent population decline, while values less than one represent population stability or population increase. Further details on the methods' assumption and R code used can be found at McPherson & Myers (2009).

2.5 Life history information

Biological information about the giant grouper were collated from all available archival sources and grouped into four life history categories: i) feeding habits, ii) habitat use, iii) behavior towards fishers, and iv) reproduction. A comparative table was created to facilitate data analysis. For each category, the information from archival sources was compared with published literature on a closely related grouper species, the Atlantic goliath grouper (*E. itajara*), to evaluate biological similarities and differences between species.

3. Results

From the standardized online TROVE search, a total of 1233 newspaper articles covering a period of 104 years, from 1854 to 1958, were sourced. Of these, 261 articles provided quantitative catch data for the giant grouper. No giant grouper records were found from the manual scanning of more recent newspaper articles. The earliest newspaper article was a report in 1854 by the *Moreton Bay Courier* in the Brisbane River. Giant grouper catches were commonly reported in total weight (n = 195 articles), with fewer reports detailing total lengths (n = 66).

From the fishing magazine article search, 24 articles were found which reported information on the weight of the giant grouper caught. Catch reports from fishing magazines occurred sporadically between 1986 and 1993.

The *F.I.S Endeavour* fished the coast of Queensland from June to September 1910. Due to the benthic composition along the Queensland coast, consisting primarily of reef or rocky bottom, the *F.I.S Endeavour* used lines and rods instead of trawls for its experiments. The research vessel carried out five fishing trips and the results of each trip were reported as ‘cruise’. Of these, only two cruises reported catches of giant grouper.

Among archival sources, newspapers reported giant grouper catch data the most consistently through time (Fig. 1). Catch data from these reports consisted of recreational catches only, with no commercial catches reported during the study period. Catch data from magazines and the *F.I.S Endeavour* were excluded from further statistical analyses given i) the low number of observations in both data sets and ii) a 28-year time gap between the most recent newspaper report (1958) and the first magazine record (1986).

3.1 Catch trends

From 1854 to 1958 the mean weight reported of the largest grouper showed no significant trends over time ($n = 74$, $F = 0.18$, $df = 62$, $p = 0.66$, Fig. S1 for model validation plots). The average grouper weight landed throughout the study period was 142 kg (95 % confidence interval = 133 -153) (Fig. 2). The smallest catch reported was a 9 kg grouper caught in 1905 in Moreton Bay, while the largest grouper reported was a 362 kg individual caught in 1931 in Gladstone.

When transforming weights to lengths ($n = 253$), the overall density distribution of the data displayed a skew towards large grouper sizes (Fig. 3A); lengths between 141.68 cm and 180.23 cm represented 75% of the total catch data. The smallest grouper was estimated at 63.69 cm, while the largest grouper was estimated at 229.28 cm in total length. In terms of grouper size categories, 33% of the catch data were classified as *optimum size*, 10% were *mature*, 6% were *mega-spawners*, and 4% were classified as *immature*.

Of the four giant grouper size categories, only two categories showed significant changes in the probability of reporting over time, immature ($\chi^2 = 3.67$, $p = 0.05$) and mature ($\chi^2 = 4.67$, $p = 0.03$) (Fig. 3B). The probability of reporting an immature grouper decreased from 0.26 (95% CI = 0.07 - 0.62) in 1866 to 0.02 (95% CI = 0.01 - 0.09) in 1958. For the mature size class, the probability of reporting increased from 0.04 (95% CI = 0.01 - 0.21) in 1866 to 0.33 (95% CI = 0.18 - 0.51) in 1958. While no significant changes were observed for the optimum size and mega-spawner size categories, the probability of reporting an optimum size class remained relatively high throughout the time series at approximately 0.62 (95% CI = 0.49 – 0.72), compared with the probability of reporting a mega-spawner which remained relatively low at approximately 0.11 (95% CI = 0.05 – 0.21).

3.2 Probability of capture

From 1860 to 1958 the probability of capturing giant grouper during a snapper outing showed a significant decline over time ($\Psi^{Gr} = P(Gr|Sn)$, $x^2 = 421.97$, df = 1, $p < 0.0001$). Probabilities declined from 0.81 (95% CI = 0.84 - 0.92) in 1860 to 0.02 (95% CI = 0.01-0.02) in 1958, an overall decline of 97.5% throughout the time-series (Fig. 4B).

No significant trends were found in the probability of capturing snapper in a grouper outing over the study period ($\Psi^{Sn} = P(Sn|Gr)$, $x^2 = 3.18$, df = 1, $p = 0.07$) (Fig. 4B), which remained at approximately 0.18 throughout (95% CI = 0.16 - 0.20).

The probability of co-occurrence of giant grouper and snapper in a given species' fishing trip declined significantly through time ($\Psi^{Gr,Sn} = P[(Gr \cap Sn) \mid (Gr \mid Sn)]$, $x^2 = 109.21$, df = 1, $p < 0.0001$) (Fig. 4C). The highest co-occurrence probability was estimated in 1860 at approximately 0.26 (95% CI = 0.21 - 0.31) and the lowest probability was recorded in 1958 at approximately 0.04 (95 % CI = 0.03 - 0.04).

3.4 Magnitude of population decline

The results from the Mcpherson and Myer's (2009) approach showed signs of giant grouper population decline commencing as early as 1910 (Fig 5). Prior to 1910, values were below 1, suggesting that the giant grouper population could have been stable at the beginning of the study period. From 1910 to 1935, the model showed a two-fold decline in the relative abundance of giant grouper (95% CI = 1.27 – 4.04). During the World War II period (from 1939 to 1945), the model estimates approached the threshold (1), suggesting an increase in the giant grouper population. Following the post-WWII era (>1945), the model estimated a four- to 47-fold decline in population between 1945 and 1954.

3.5 Life history information

Of the 261 articles that provided quantitative and qualitative information about the giant grouper, nine explicitly described feeding habits, three mentioned habitat use and six described grouper behavior towards fishers and divers. No articles were found with descriptive information about reproduction.

Feeding habits

Giant grouper prey information was obtained from articles that explicitly mentioned stomach content (Table 1). According to the articles, the giant grouper prey upon sharks and stingrays (unspecified), butterfish (Monodactylidae), black bream (Sparidae), mullet (Mugulidae), blackfish (Girellidae), and mangrove crabs (Portunidae). The most common prey items mentioned in the articles (6 out of 9 articles) were mangrove crabs. When comparing prey items of giant grouper with information found for the Atlantic goliath grouper, similar responses were found. Crustaceans (e.g., crabs and lobsters) also constituted the preferable prey item of the Atlantic goliath grouper in Florida, Brazil, and Belize.

Behavioral aspects

All articles (n = 6) that described behavioral aspects of the giant grouper focused on the aggressive behavior towards divers (e.g., pearl divers). Articles particularly described the giant grouper's persistence and determination (sometimes referred to as curiosity) to approach divers. Only one article mentioned physical attacks on pearl divers in the northern region of Queensland (26 March 1929, *The Brisbane Courier*). Several studies using fisher's local ecological knowledge on the Atlantic goliath grouper, also documented aggressive behaviors toward divers (e.g., spearfishers) in Mexico, Brazil and Florida (Table 1).

Habitat use

Three articles provided detailed information on habitat use by the giant grouper. One article mentioned that giant grouper was commonly caught during snapper fishing (e.g., in rocky offshore systems) and could also be found in inner and outer bay areas and creeks (e.g., coastal systems). Other articles mentioned that giant grouper commonly inhabit areas with high structural complexity, such as shipwrecks and caverns. Descriptions of habitat use by the Atlantic goliath grouper showed similar patterns (Table 1), including inshore habitats with low salinity waters.

4. Discussion

Using archival data sources in combination with biological inferences and statistical approaches, this study uncovered the heretofore hidden decline of the giant grouper population in Queensland over a period of 92 years. Archival data are commonly publicly available but often underused by fisheries researchers. By analyzing historical sources, it is possible to characterize and identify population trends that have been hidden in plain sight.

Historical sightings of the giant grouper were commonly reported from 1854 to 1858, while giant grouper encounters after 1960s remained sparse. These historical sightings consisted mostly of reports from the recreational fishing sector, with no evidence of a commercial fishery for the species for the study period. The reported weight of the largest giant grouper caught varied greatly throughout the study period. Unlike other large-bodied grouper species (e.g., Atlantic and Pacific goliath groupers), which have been targeted by fisheries over extended periods of time (McClenachan, 2009b, Castellanos-Galindo et al., 2018), the giant grouper fishery in Queensland was primarily considered an incidental catch by recreational fishers. Nevertheless, giant grouper catches would commonly be reported and regarded as significant landings, even when it was not the primary targeted species. For example, *The Moreton Bay Courier* in 1854 reported:

> "A very large fish, of the kind called a 'groper' was caught yesterday at South Brisbane, by some men belonging to the ketch Sarah, who were fishing for a shark. The monster, for such it was in size, weighed over two hundred and ninety pounds. It was quickly cut up and distributed and found to be excellent eating."

4.1 The potential effects of fishing biologically significant grouper size classes

Most historical articles provided information on giant grouper catches in units of weight, but in this work a weight-to-length conversion was used to investigate the vulnerability of specific giant grouper size classes to fishing. Further, understanding how fishing disproportionately affects a specific size class can inform about the effects of fishing on the overall sustainability of the population. For example, the continuous targeting of the largest individuals in the population can cause severe population declines, loss of genetic diversity, alter population demography, and limit fertilization success (Hauser et al., 2002, Hamilton et al., 2007, Price et al., 2019). These effects are often exacerbated in species with sex-changing strategies (e.g., female first), as they have naturally skewed sex ratios, consisting of mostly females and fewer larger males (Alonzo et al., 2008, Kindsvater et al., 2017). Given that most grouper species are protogynous hermaphrodites (i.e., female-first) and the importance of length data for fisheries management, the length assessment demonstrated that biologically distinct giant grouper size classes were disproportionately affected by the fishery throughout the study period. Here, the potential impacts of historical fishing selectivity and how it might have contributed to an overall population decline are discussed from a biological perspective.

From 1866 to 1958, the giant grouper fishery was characterized primarily by the targeting of the largest individuals in the population, including mature, and optimum-size individuals as well as mega-spawners. Selective removal of the largest individuals from a population (e.g., males) has been related to limitation of reproductive success, even at low levels of fishing mortality (Alonzo et al., 2008, Chong-Montenegro & Kindsvater, 2022). For example, populations of the gag grouper (*Myteroperca microlepsis*) have experienced severe shifts in the population sex ratio largely caused by sperm limitation due to the mass removal of large males in the population (Heppell et al., 2006). Similar concerns about possible sperm limitation have been raised for several grouper species, including *Epinephelus fuscoguttatus* and *E. guttatus* (Beets & Friedlander, 1999, Alonzo & Mangel 2004, Pears et al., 2006). For the giant grouper fishery, the probability of reporting optimum size and mega-spawners size classes remained consistent over time. This indicates that large individuals were continuously removed over the study period. There are two potential reasons for this: 1) The number of adults in the population was large enough not to be affected by fishing, or 2) there was a spatial expansion of the fishery that allowed for catching and reporting the largest individuals over the time period. We argue that the case for the giant grouper is most likely the latter, given the spatial distribution of the articles reported over time (Fig. S2), and a potential newspaper bias toward reporting the largest individuals of the catch. Overall, the results demonstrated that over 92 years, the giant grouper population sustained selective fishing (i.e., the probability of reporting a specific grouper size class over time) of most of the adult population (i.e., mature, opt. size and mega-spawners), potentially contributing to a reduction in the fertilization success of the population at local scales.

During the early development of the giant grouper fishery, from 1866 to 1910, signs of growth overfishing were detected, as shown by the significant decline in the probability of reporting immature fish. Growth overfishing occurs when fish are harvested before reaching the size at which they can yield maximum sustainable yield (Diekert, 2012). Although, it is possible that this trend might be attributed to newsworthiness declines in the reporting of immature individuals, the results from the McPherson & Myers (2009) approach further suggest a severe giant grouper population decline commencing as early as the 1910s and lasting approximately until the 1940s (pre-WWII). During the same time period, the probability of catching mature fish also increased. The combination of these observed trends suggests signs of potential recruitment overfishing. Recruitment overfishing occurs when a large percentage of mature fish are removed by the fishery, limiting the ability of a population to replenish itself (Froese, 2004). This period of population decline coincided with the establishment of recreational fishing clubs across the region and the expansion of fishing effort towards new and unexploited fishing grounds (Clark, 2017, Thurstan et al., 2018, Fig. S2). As recreational fishing activities became increasingly popular in the early 20th century, it is possible that fishers might have targeted unexploited giant grouper populations in these new fishing locations.

4.2 Estimating probability of encounter as index of relative abundance

Giant grouper occurs at naturally low levels of abundance, even in unexploited fishing grounds (Fennessy et al., 2008). Given this observation, changes in the relative abundance of the already rare giant grouper were tested using snapper (a more abundant and popularly targeted species) as an indicator of underlying population trends. Similar approaches have been used to track changes in the relative abundance of uncommon species (e.g., red steenbras, *Petrus rupestris*) within commercial and recreational fisheries (Kerwath et al., 2019). The results demonstrated that the probability of catching giant grouper during a snapper outing remained high for the first part of the time series (1870-1900) before rapidly declining after the 1910s. This decline might be attributed to the early development of the snapper fishery in combination with fishers' attitude towards fishing. From the 1870s until the 1920s, snapper fishing was regarded as a *sport*, often described as "more slaughter than sport", with many fishers' aiming to catch as many fish as possible (Thurstan et al., 2018). This attitude might have driven fishers decisions to target and land every fish in the catch, including giant grouper (Thurstan et al., 2018). Given that giant grouper might have already occurred at low levels of abundance early in the time period, the initial and severe extraction of the few but large individuals might have been sufficient to inhibit the ability of the giant grouper population to replenish itself. Similarly, other grouper species have experienced acute local depletions. For example, since 1985 Pacific goliath grouper has all but disappeared from fisheries landings in the Gulf of California (Sala et al., 2004), and the Atlantic goliath grouper off the coast of west Africa has been declared functionally extinct (Craig et al., 2009).

Whilst signs of population decline of giant grouper were detected from the 1900s until the early 1940s, the results suggested population recovery during World War II (1939-1945). These fluctuations in the population might be associated with changes in the reporting and fishing effort over time (e.g., spatial expansion of fishing effort over time [Fig. S2]). During WWII, newspapers in Queensland shifted their focus onto more global news, with much less reporting effort on local recreational fishing activities (Thurstan et al., 2017, Chong-Montenegro et al., 2022c). Declines in fishing effort in Australia during WWII also occurred (Klaer, 2001), potentially alleviating some fishing pressure on the giant grouper population.

In addition, while studies have commonly explored population decline based on the largest fish reported over time (e.g., McClenachan, 2009a, Giglio et al., 2017), for many underrepresented species within a fishery (i.e., non-target species), size trend assessments might hamper our ability to detect population change. Therefore, to avoid drawing incorrect population assumptions, it is necessary to evaluate species trends from a broader fisheries context, such as assessments of the probability of capture as a proxy of population declines.

Furthermore, archival sources are often narrative-driven, offering further observations into the social, ecological, and biological accounts of rare species (Sáenz–Arroyo et al., 2005, Moore & Hiddink, 2022). Qualitative descriptors derived from newspaper articles between 1866 and 1956 revealed detailed information on the life history of the giant grouper. The biological information derived from archival sources was compared with published scientific literature of a data-rich grouper, demonstrating similarities in the biology and ecology of these sister species. Therefore, historical descriptions can be used to inform knowledge gaps on the behavior and biology of a data deficient species.

4.3 Archival sources and their potential use for the conservation of data deficient species

For many rare species, such as the giant grouper in Queensland, historical sighting records are often the most common source of information that can help inform about the species' population trajectory over time. Quantitative assessments of historical sighting records have provided valuable information about the timing and occurrence of extinction events when species' abundance data are deficient (Ferretti et al., 2016).

Inferring the extinction risk of a species allows for informed decisions to be made regarding the allocation of time and monetary resources for conservation strategies (Cheung et al., 2005; Boakes et al., 2015). Investigations of historical population trends using archival sources can inform the conservation status of species at risk, identify localized areas where extinctions might have occurred but were previously unrecognized, identify extrinsic threats (e.g., fishing, environmental degradation) and determine the time and occurrence of population declines. By examining historical population trends, it is also possible to identify whether a population has experienced periods (e.g., generations or decades) of population stabilization at significantly reduced population levels compared to its historical abundance. This effect has been defined as the "ski jump" effect and can have significant implications for the assessment of the conservation status of a species using the IUCN Red List Criteria (Sadovy de Mitcheson et al., 2020). For example, assessing the conservation status of an already significantly declined population over short periods can result in wrongly classifying the species as Least Concern when no changes in the population have been identified over three generations (see Red List assessment, 2022). Thus, historical reconstruction of population trends can be used for determining the true conservation status of a species and for evaluating conservation effectiveness by improving or adjusting population recovery efforts and targets (Lee et al., 2017).

In addition, this study highlights the importance of regional assessments of Data Deficient species to uncover local population declines and the social-ecological drivers behind these trends. This research has identified that fishing harvests in combination with size-selective fishing can lead to severe population declines for giant grouper across Queensland. However, the giant grouper is widely distributed across the Indo-Pacific, and it is likely that local populations are experiencing extrinsic threats that are unique to specific areas. For example, wild-caught groupers from Indonesia are commonly traded in Hong Kong, China, and Taiwan for the live fish trade (Khasanah et al., 2020, Sadovy de Mitcheson et al., 2020). It is, therefore, imperative to investigate the historical exploitation of vulnerable fish species at local scales and determine the drivers of such declines. Thus, local policies can be created that address the conservation of the species while respecting the social-cultural norms of specific areas.

5. Conclusion

Using quantitative and qualitative information derived from archival sources, this work reconstructed catch trends of the giant grouper in Queensland, Australia, over 92 years. These results demonstrated how specific grouper size categories sustained pressure over time and inferred the potential biological effects of selective fishing on the population demographic that led to population declines. Further, the magnitude of decline that the giant grouper population experienced over time was evaluated using two robust modelling approaches for sightings records.

Lastly, this work highlights how quantitative and qualitative assessments of historical archives can provide valuable information about the timing and occurrence of population declines, recoveries and extinction events when species' abundance data are deficient or when species occur at naturally low population densities, such as the giant grouper. Given the lack of fisheries-dependent data for many rare species, archival sources in combination with statistical approaches and biological inferences, can help uncover the population trajectory of species at risk. In addition, archives provide context into the social and cultural processes of how these fishing events unfolded, therefore, shedding light on the social-cultural factors behind these trends. Thus, to maintain biodiversity and set recovery targets for species at risk, it is necessary to evaluate the magnitude of decline that a population has experienced in the past and determine the extrinsic social-ecological threats associated with these trends. Ultimately, historical trends can thus be used to evaluate conservation effectiveness by improving or adjusting population recovery targets.

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Tables:

Table 1. Life history attributes of the giant grouper (*Epinephelus lanceolatus*) collated from newspaper articles published in Queensland, Australia, and compared with published literature of the Atlantic goliath grouper (*Epinephelus itajara*).

Epinephelus lanceolatus			***Epinephelus itajara***	
Reference	**Description**	**Life history attribute**	**Description**	**Literature**
16 April 1872, The Brisbane Courier	"It measured [the grouper], we are told, 8 feet 4 inches in length, 6 feet 2 inches in girth, and so must have been rather a corpulent individual. Its rotundity is partly accounted for, however, by the contents of its stomach, viz., **two young sharks**, one over three feet long, likewise **eight or nine crabs**, whole."	Feeding habits	Crustaceans, slipper lobsters, turtle, shrimps, catfish, stingray	Sadovy & Eklund (1999)
9 December 1910, Darling Downs Gazette	"In the stomach [of the grouper] were found **15 large butterfish** weighing about 1.75 lb, **three black bream**,	Feeding habits	Lobsters, spadefish, octopuses and catfish, mullets and shrimps	Gerhardinger et al. (2006)

	three mullet, a **large blackfish**, and **a large mangrove crab** about 12 inches across the legs."			
28 May 1927, The Brisbane Courier	“I have seen outside Point Lookout a groper [grouper] so large that the porpoises seemed small alongside of him... **They are mostly caught on the schnapper grounds**, about 40lb. to 90lb. weight, no more, and from the enormous size of their mouth can take in any bait or hook. **These fish also come into the Bay and the mouths of the rivers and creeks,** and some very large ones up to 130 lb weight have been inside."	Habitat use	"*E. itajara* is found in the inner and outer bay, from offshore/marine to low salinity estuaries waters"	Gerhardinger et al. (2006)

19 February 1933, Sunday Mail	"These gropers [groupers] live in **caverns** in the sides of coral reefs, deep down below the surface of the water."	Habitat use	"*E. itajara*, in general prefer holes, caves, or places where they can find shelter"	Sadovy & Eklund (1999)
21 June 1919, Gympie Times and Mary River Mining Gazette	"On the other hand nobody would think the bovine, slow moving groper [grouper] **would be dangerous**: but it is hated by divers for its inveterate curiosity and determination. The fish's practically toothless jaws can take a man's hand off. None of the tricks which scare the devil out of sharks, such as a squirt of compressed air from the valves, will work with a groper [grouper]. He will stay and nuzzle a man all over, looking for something to munch off."	Behavior	"Occasional aggressive behaviors were associated with individuals cornered in caves or previously speared."	García-Téllez et al. (2022)

List of figures legends

Figure 1. Time series of historical catch records for the giant grouper (*Epinephelus lanceolatus*) by data source in Queensland. Size of bubbles represents the number of observation per year. Rectangle shows a 28-year time gap between the most recent newspaper report (1958) and the first magazine record (1986).

Figure 2. Generalized linear model of the mean weight of largest grouper (*Epinephelus lanceolatus*) caught in total kilograms reported through time in Queensland. The model was fitted with a normal error distribution and logarithmic link function. Mean grouper weight estimates are shown in the dashed grey line. Grey shading represents 95% confidence intervals of the mean. Open circles represent raw catch data per year.

Figure 3. A) Density distribution of the giant grouper lengths, and lengths categories. B) Logistic regression showing historical trends in the probability of reporting a giant grouper size category. Grey areas represent 95% confidence intervals; red asterisks (*) show significant trends ($p < 0.05$).

Figure 4. Logistic regression showing trends in the probability of capturing a grouper in a snapper outing (A), the probability of capturing a snapper in a grouper outing (B), and the probability of co-occurrence (C) in a grouper or snapper outing through time. Grey area shows 95% confidence intervals. Black dots represent year probabilities. Venn diagrams depict individual and co-occurrences probabilities. Gr = Giant grouper; Sn = Snapper, P = Probability. Note that y-axis scale differs among plots (A, B, and C).

Figure 5. Population trends of the giant grouper (*Epinephelus lanceolatus*) through time. A) Estimates of relative abundance are represented as black dots with 95% confidence intervals. Horizontal red dashed line depicts a value of 1, values above the horizontal line represent stable or increasing populations, whereas values below 1 represent population declines. B) Number of reported sightings (catches) per year for the giant grouper in Queensland, Australia.

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