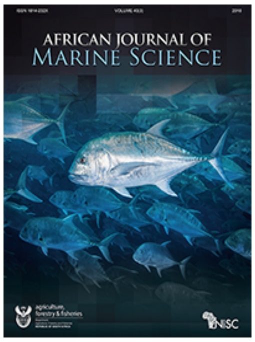

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Short communication

Quantifying the largest aggregation of giant trevally *Caranx ignobilis* (Carangidae) on record: implications for management

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The giant trevally *Caranx ignobilis* (Forsskål) is an important apex predatory fish typically associated with coral reef communities. It is prized in recreational and commercial fisheries, yet little is known about its aggregation dynamics and susceptibility to fishing pressure. This study reports on a previously undocumented aggregation of mature giant trevally observed over a period of eight years (2010–2017) at Ponta do Ouro Partial Marine Reserve in southern Mozambique. The aggregation is one of the few recorded for this carangid in the western Indian Ocean and represents the first subtropical aggregation of giant trevally. The aggregation is also the largest recorded for this species, with up to 2 413 individuals representing an estimated biomass of approximately 30 tonnes. The size and predictability of this annual aggregation make it vulnerable to overexploitation and point towards the need for an appropriate conservation management strategy.

Keywords: Carangidae, fish aggregation, fisheries management, marine protected area, Mozambique, predatory teleosts, site fidelity, video observations

Online supplementary information: A dive log of all observations at the study site (Table S1) and an image revealing colour dimorphism and pairing between giant trevally (Figure S1) are available at https://doi.org/10.2989/1814232X.2018.1496950

Introduction

The giant trevally *Caranx ignobilis* (Forsskål 1775) is a large predatory fish, reaching up to 170 cm total length and 87 kg (Meyer et al. 2007; Murakami et al. 2007). As such, it is one of the largest top predatory teleosts associated with coral reefs throughout its tropical to warm-temperate Indo-Pacific distribution and it plays a key predatory role in these ecosystems (Sudekum et al. 1991; Maggs 2013; Froese and Pauly 2018). The giant trevally is prized by recreational anglers for its strong fighting abilities and by artisanal and commercial fishers for its large size, resulting in considerable demand for this species throughout its distribution (Sudekum et al. 1991; Gaffney 2000; Meyer et al. 2000; Maggs 2013; FAO 2014). To date, the giant trevally has received substantial research attention in the Pacific Ocean, yet despite its ecological importance and fishery value, little information exists for this species in the western Indian Ocean (Sudekum et al. 1991; Wetherbee et al. 2004; Meyer et al. 2007; Maggs 2013; Lédée et al. 2015). Furthermore, little is known about the aggregation dynamics of this carangid or its vulnerability to fishing during aggregation events (Claydon 2004; Maggs 2013).

Mass aggregations are common among coral-reef-associated fishes and may be represented by hundreds or many thousands of conspecifics concentrating within a small area. Fish aggregate primarily to enhance feeding, safety or reproduction (Pitcher et al. 1982; Pitcher 1986; Domeier and Colin 1997; Claydon 2004). During aggregation (especially for spawning) fish might be susceptible to, and might not recover from, overexploitation by fisheries (Rowe and Hutchings 2003; Sadovy de Mitcheson et al. 2008). The economic, biological and ecological value of fish aggregations, coupled with their vulnerability to fishing, necessitate appropriate management of known aggregation sites (Sadovy de Mitcheson 2016). Thus, understanding the dynamics of such aggregations is essential for improving current conservation management practices (Domeier and Colin 1997; Sadovy de Mitcheson and Domeier 2005).

The aim of this study was to investigate the persistence, size and biomass of a giant trevally aggregation in the Ponta do Ouro Partial Marine Reserve (PPMR), southern Mozambique (Figure 1), in order to improve our understanding of the aggregation dynamics of the species.

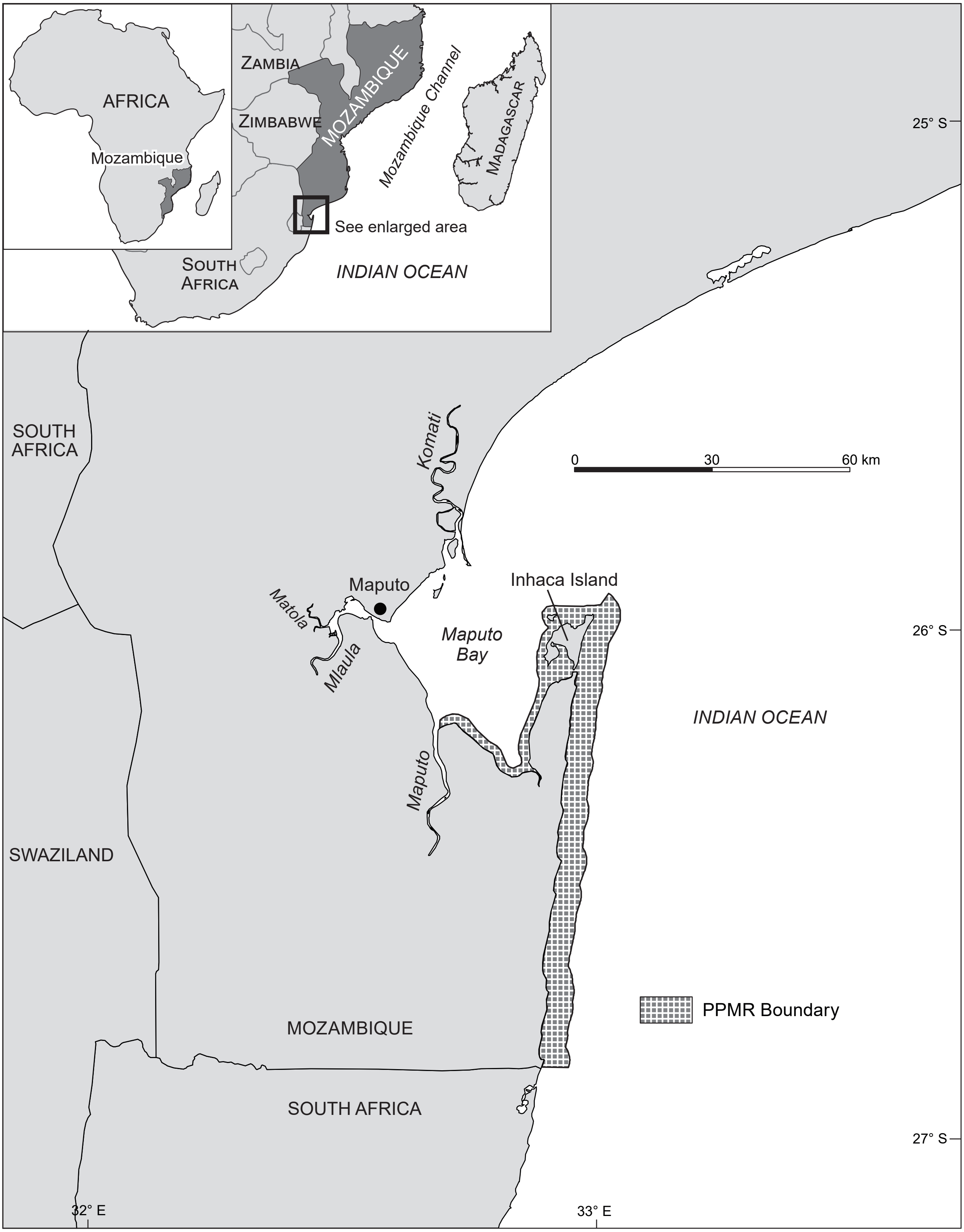

Figure 1: Location of the Ponta do Ouro Partial Marine Reserve (PPMR), situated between Maputo Bay, Mozambique, and the South African border, where the giant trevally aggregation was observed

Materials and methods

Study site

This study took place in southern Mozambique, within the Ponta do Ouro Partial Marine Reserve (PPMR). The PPMR is located within a biogeographical transition area referred to as the Delagoa Bioregion (Turpie et al. 2000) and encompasses 98.5 km of coastline extending from the South African border in the south to the Maputo River in the north (DNAC 2009). Primary reef formations are characterised by submerged late Pleistocene beach rock that is colonised by a thin veneer of Indo-Pacific corals (Ramsay and Mason 1990; Ramsay 1994) and are associated with a diverse Indo-Pacific fish community (Floros et al. 2012). Recreational fishing within the PPMR is restricted to multiple-use zones and is subject to partial restrictions (only pelagic fish may be targeted, including giant trevally) and bag limits (10 fish per person per day). No industrial or semi-industrial fishing is allowed, and commercial fishing is restricted to multiple-use zones for registered small-scale fisheries from local communities (DNAC 2009). However, the relatively high recreational and commercial value of the giant trevally makes the species vulnerable and potentially subject to illegal and unregulated fishing pressure in the region.

Data collection and abundance estimates

Observational dives were conducted at the study site using SCUBA and snorkel gear, from January 2010 to December 2017. In total, 140 diving days were logged over this period, primarily during austral spring and summer (November to May). Dives were conducted between sunrise and sunset (due to vessel restrictions as well as diving and boating safety) and when the wind speed was less than 15 knots and water visibility exceeded 20 m. An aggregation was considered to be present when there was a considerable increase (at least ten-fold) in the typical observed density of giant trevally in the area (Domeier 2012).

The frequency of occurrence of the giant trevally aggregation in relation to the phase of the moon was assessed for observations made between 2011 and 2016, using the statistical software package Oriana 4 (Kovach Computing Services). Rao's spacing test (Batschelet 1981) was used to test for uniformity in the temporal data: that is, testing the null-hypothesis that aggregations were distributed evenly over all lunar phases. The level of statistical significance was determined from a table of simulated critical points (Russell and Levitin 1996) with α set at 0.05.

When the aggregation was sighted, the date, time and location were recorded. When possible, video footage of the aggregation was recorded using a Canon EOS 5D Mark II with a 17–40 mm rectilinear lens contained in a Subal underwater housing. In general, the giant trevally aggregation was cautious of divers and it did not come close enough for video footage to be recorded in 2012 and 2016. Thus, the abundance of giant trevally in the aggregation was estimated from video recordings collected in 2011 (n = 1 recording), 2013 (n = 3), 2014 (n = 3), 2015 (n = 1) and 2017 (n = 4). Abundance was estimated using three metrics. First, the standard 'MaxN' (maximum number) approach (Priede et al. 1994; Ellis and DeMartini 1995) was used to identify the frame in which the greatest number of individual fish was observed (Cappo et al. 2006). The second estimate (a 'running count') was based on a derived method where video footage was scrutinised for short segments in which the giant trevally shoal moved in one direction relative to the camera's field of view, analogous to a diver-operated video transect (Langlois et al. 2010). The third estimate (a 'volume count'), also derived, was based on the geometry of the shoal (roughly spherical) and was used to include in the abundance estimate those individuals that may have been obscured by others closer to the lens. For the 'volume count,' the number of fish recorded side-by-side along a single axis (z axis) of the shoal, in a single video frame, was used to represent the diameter of the shoal. Visual assessment of video footage indicated that fish length (x axis) was approximately three-times greater than dorsoventral height (y axis) or lateral width (z axis). Therefore, the 'volume' of fish (as a proxy for abundance) was estimated using the equation for volume of an ellipsoid (i.e. unequal radii), where anterior–posterior (x axis) radius was assumed to be one-third of the horizontal and vertical radii (i.e. the x axis could hold one-third the number of fish as the y and z axes), as follows:

$$\text{Abundance}(\text{volume}) = \frac{4}{3}\pi\frac{r_x}{3}r_y\,r_z \quad (1)$$

where r_x, r_y and r_z represent axial (anterior–posterior) radius, vertical radius and horizontal (side-by-side) radius, respectively. Maximum abundance estimates for each video recording are presented.

Additionally, in December 2017, stereo video footage of the aggregation was recorded (four separate video recordings) with a calibrated stereo video system (using SeaGIS CAL software and calibration cube). The stereo video footage was then analysed using SeaGIS EventMeasure software to measure the fork lengths of 345 individual fish. Fork lengths were then converted to individual weights (van der Elst and Adkin 1991) and the biomass of the aggregation was estimated by multiplying the mean weight of individual fish by the abundance estimates.

Results

Over the eight-year observational period (2010–2017) the aggregation of giant trevally was observed 40 times at the same site, every year between November and December and in February in one year (2014). Absence of the aggregation was noted on all other observational dives (n = 100) throughout the study period (Supplementary Table S1).

Observations of the giant trevally aggregation appeared to be more frequent between the first and third quarters of the lunar cycle (Figure 2). However, the results from Rao's spacing test did not support the hypothesis that the data were unevenly distributed or biased relative to a particular lunar phase ($p > 0.05$).

The three different metrics used to estimate the abundance of giant trevally provided estimates ranging from 261 to 2 413 individuals (Table 1). MaxN gave the lowest estimates, with a mean of 428 fish (SD 157) and maximum of 835 fish (Figure 3). The running counts were variable but were consistently higher than the MaxN counts, with a mean of 750 fish (SD 268) and a maximum of 1 329

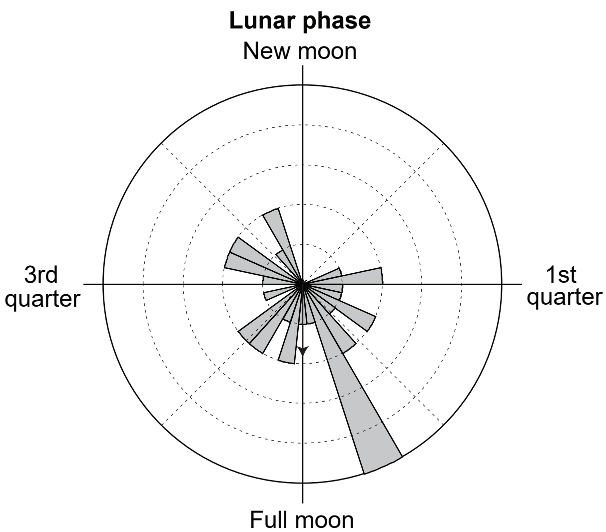

Figure 2: Frequency distribution of the giant trevally aggregation sightings at the study site relative to the lunar phase

Table 1: Abundance estimates of the giant trevally aggregation using three different methods (MaxN, running count, and volume count). Multiple counts within some years were based on separate video recordings taken on separate days. NA indicates that a suitable video segment was not available.

Year	Month	MaxN	Running count	Volume count
2011	December	451	1 329	1 018
2013c	November	449	955	715
2013a	December	349	612	589
2013b	December	358	676	715
2014a	December	304	NA	715
2014b	December	401	455	1 396
2014c	December	445	638	715
2015	December	835	497	2 413
2017	December	261	841	2 405
Mean (SD)		428 (157)	750 (268)	1 187 (692)

fish. Volume counts gave the highest and probably the most-realistic estimates, with a mean of 1 187 fish (SD 692) and a maximum of 2 413 fish.

Stereo video recordings were used to measure the fork lengths (FL) of 345 individual fish within the aggregation. Fork lengths ranged from 62.8 to 131.2 cm with a mean of 85.5 cm (SD 10.5). Of the 345 fish measured, the majority (77%) were between 80 and 100 cm FL (Figure 4). Weights of the fish, estimated from FL, ranged from 4.87 to 43.97 kg, with a mean individual fish weight of 12.77 kg (SD 5.19). The total biomass of the aggregation was estimated to range between 3 882 and 30 814 kg.

Discussion

This study reports on the first record of a subtropical aggregation of giant trevally in the Southern Hemisphere. The aggregation represented a spatially and temporally predictable aggregation of conspecific mature-size fish, and was present most frequently between the first and third quarters of the lunar cycle, during November and December of each year, with evidence that it may persist through to February. The seasonal timing and longevity (2 to 3 months) of the aggregation during the austral summer months are consistent with previously reported giant trevally spawning aggregations in other regions (Sudekum et al. 1991; da Silva et al. 2014). Additionally, there was some evidence to suggest that fish in the aggregation were spawning (two male giant trevally captured from the aggregation in December 2016 freely released sperm when handled, and colour dimorphism and pairing was observed in the aggregation [Supplementary Figure S1]). This suggests that the purpose of the aggregation was for spawning, but additional direct evidence of spawning is required.

Aggregation size

Giant trevally are known to form dense aggregations during the spawning season (Claydon 2004; Meyer et al. 2007; Dale et al. 2011). However, the aggregation of adult giant trevally recorded here is considerably larger than any previously reported aggregation of this species, with examples from elsewhere being >100 fish in the Philippines (von Westernhagen 1974) and >1 000 fish in northern Mozambique (da Silva et al. 2014). Despite the reported aggregation being the largest on record, taking into consideration the various constraints of each abundance metric presented here (cf. Squire 1978; Denny and Babcock 2004; Cappo et al. 2006; Schobernd et al. 2014), our estimates are likely underestimates of its true abundance, and the aggregation may in reality comprise more individuals than the counts presented. It is also possible that the aggregation exhibits a gradual turnover of individuals throughout the protracted aggregation period, in which case the absolute number of giant trevally taking part in the aggregation may be higher still. Nonetheless, with up to 2 413 individuals at one point in time, this aggregation is likely of major ecological significance, both to the species and to the ichthyofaunal community at the aggregation site.

Biomass

The mean length (85.5 cm FL [SD 10.5]) of the giant trevally was found to be consistent with the mean length of 24 fish captured from the aggregation (78.4 cm FL [SD 12.4]). This suggests that the stereo video system and software could be used to accurately measure the size of fish within the aggregation and provide a relatively accurate estimate of giant trevally biomass within the aggregation. Additionally, all 345 fish measured in the aggregation in December 2017 were larger than the size at 50% maturity (Maggs 2013), suggesting that all individuals in the aggregation were reproductively mature, providing further evidence to suggest that the purpose of the aggregation is for spawning.

Ecological significance

The seasonal presence of up to 2 413 mature giant trevally with a maximum estimated biomass of 30 814 kg, as described in this study, represents a significant increase in the biomass of top predatory fish within a spatially restricted

Figure 3: A screen shot from video footage of the giant trevally aggregation at Ponta do Ouro Partial Marine Reserve, southern Mozambique, in December 2015; the MaxN estimation from this video sequence was 835 fish

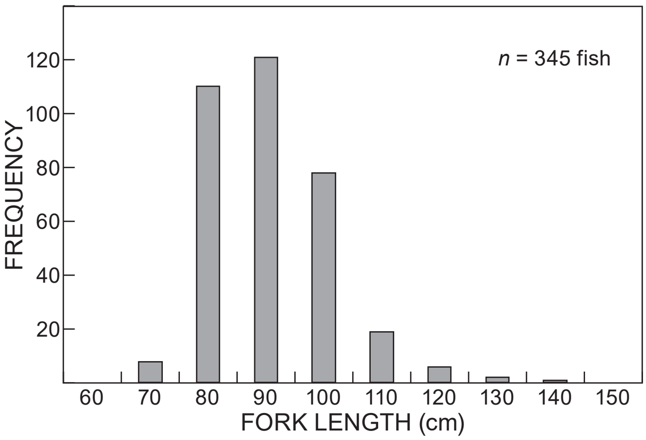

Figure 4: Frequency histogram of fork lengths of the giant trevally in the aggregation in December 2017, as measured from stereo video footage

coral reef habitat. Such an influx of a top predator may play an important role in structuring the local community dynamics through predation (Dulvy et al. 2004; Bascompte et al. 2005). Additionally, the giant trevally aggregation may facilitate various unique trophic interactions during the aggregation period (Claydon 2004; Heyman et al. 2005; Domeier 2012). Indeed, a seasonal increase in the number of bull sharks *Carcharhinus leucas*, which likely prey on the giant trevally, is associated with the giant trevally aggregation (Daly et al. 2013, 2014). The seasonal influx of so many large predatory fish must certainly be of importance to the local marine community in the PPMR, and further studies are required to elucidate the broader ecological role that the aggregation plays.

Management implications and summary

The spatially and temporally predictable aggregation of this economically important fishery species makes the giant trevally highly susceptible to exploitation by recreational, artisanal and commercial sectors, and thus deserves prioritised management intervention (Meyer et al. 2007; Grüss et al. 2013). Targeting fish during aggregations is common, and several families, for example groupers (Epinephelidae), face severe threats as a result (Robinson et al. 2014; Sadovy de Mitcheson 2016). Well-enforced no-take zones within marine protected areas that incorporate aggregation sites, and seasonal fishery closures during periods of aggregation, may both be effective conservation tools (Meyer et al. 2007; Robinson et al. 2008; Grüss et al. 2013). Additionally, because fish may also be subject to high fishing mortality on migration routes to and from aggregation sites, the extent of the species' functional migration area should also be considered (Claydon 2004; Nemeth 2012; Sadovy de Mitcheson 2016). As the aggregation described in this study occurs within 20 km of the international border between Mozambique and South Africa, it is likely that some fish taking part in the aggregation in Mozambique migrate from South Africa. Considering the contrasting harvesting regulations on either side of this international border, transboundary movements may render these individuals more vulnerable to exploitation in certain areas. Future studies should focus on understanding the transboundary movements of fish aggregating in Mozambique in order to align current conservation management plans. While the underlying reasons driving the fish aggregation described here are yet to be fully validated, its predictable nature along with its unprecedented size confirm both its regional significance and the requirement for management interventions to ensure its long-term persistence.

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