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Insights into the reproductive biology of the common dolphinfish *Coryphaena hippurus* Linnaeus, 1758 (Coryphaenidae), in Indian seas

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Abstract

Understanding the reproductive biology of a species aids in formulating conservation strategies and in developing sustainable culture practices. The common dolphinfish, *Coryphaena hippurus* Linnaeus, 1758, is caught all along the Indian coast in different gears such as gillnets, hooks and lines and trawl nets. This study was undertaken to examine the reproductive behaviour of the species focusing on peak spawning season, fecundity and size at first maturity. The study was based on a total of 1973 individuals collected from seven landing centers across the country. Length of females ranged from 25 to 103.5 cm TL with a mean of 74.74 cm TL, while males ranged from 31.7 to 123.5 cm TL with a mean of 74.01 cm TL. Females predominated across all months and size groups, with an average annual sex ratio of 1.9:1 (Female:Male). The estimated size at first sexual maturity (L_{m50}) was 62.6 cm TL for females and 65.9 cm TL for males. Absolute fecundity was estimated at 402,085 eggs per female and relative fecundity at 185 eggs (SD ± 85) per gram weight of female. Mature adults were observed year-round, with peak gonadosomatic index (GSI) values in August, September and January. Ova diameter study showed asynchronous spawning in the species. The results of this study provide valuable inputs for developing a species-specific fishery management plan for common dolphinfish in Indian waters.

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Introduction

Knowledge on the reproductive biology of exploited fish species helps in efficient stock management by formulating suitable measures to harvest the resources sustainably (Brown-Peterson *et al*., 2011; Kjesbu, 2016). The common dolphinfish or 'Mahi-mahi' *Coryphaena hippurus* Linnaeus, 1758 is an important pelagic species exploited from Indian seas. There are two species in the genus *Coryphaena viz*., *C. hippurus* and *C. equiselis*, under the family Coryphaenidae. Of these, *C. hippurus* dominates the landings of dolphinfish across the Indian coast, while *C. equiselis* (Pompano dolphinfish) forms a minor fishery. The *C. hippurus* fishery in India is mainly non-targeted, as these species are landed with other large pelagic fishes like tuna, seerfish, barracudas and billfishes. Major gears involved in catching dolphinfish in Indian waters are gillnets and hooks and lines on the east coast, while trawls also play an important role on the west coast (Rajesh *et al*., 2016; Saroj *et al*., 2018; Ghosh *et al*., 2022).

C. hippurus exhibits marked sexual dimorphism and the sexes can be differentiated through visual observation in the late juvenile stages. The presence of "bullhead" (strong bone crest on the top of the head) is predominantly larger in males, while females have more slender head profiles (Massutí and Morales-Nin, 1997; Molto *et al*., 2020). This sexual dimorphism is evident within a length range of 40 to 50 cm fork length (FL) (Palko *et al*., 1982; Massutí and Morales-Nin, 1997; Benseddik *et al*., 2015). The species is known to have asynchronous gonadal development with multiple spawning and males grow faster,

reaching larger sizes than females (Oxenford, 1985, 1999; Massutí *et al*., 1998). Studies on reproductive biology of dolphinfish are available from various parts of the world, such as the Western Atlantic (Oxenford, 1999; McBride *et al*., 2012; Lira Dos Santos *et al*., 2014), Eastern Pacific (Campos *et al*., 1993; Zuniga-Flores *et al*., 2011), Western Pacific (Wu *et al*., 2001; Furukawa *et al*., 2012), Mediterranean (Gatt *et al*., 2015; Benseddik *et al*., 2019) and from India (Varghese *et al*., 2013; Rajesh *et al*., 2016; Kumar *et al*., 2017; Saroj *et al*., 2018; Assana *et al*., 2021; Ghosh *et al*., 2022). These studies from India are region-specific with geographic restrictions and a comprehensive understanding of the reproductive aspects of the species from Indian waters is lacking. Hence, the present work was carried out to address this lacuna.

Materials and methods

A total of 1973 samples of *C. hippurus* were collected fortnightly from major fish landing centres of the country *viz.,* Visakhapatnam, Kakinada, Chennai, Cochin, Mangalore, Malpe and Veraval (Fig. 1) from January 2017 to December 2019. The specimens were brought to the laboratories of ICAR-Central Marine Fisheries Research Institute (ICAR-CMFRI) in the respective centres in insulated ice boxes for analysis. The total length (TL) and total weight (TW) of each specimen were measured to the nearest 0.1 mm and 0.1 g precision.

The sexes were determined by visual inspection of the dissected gonads using a five-stage classification of gonadal maturity for males and females (Brown-Peterson *et al*., 2011) as immature, developing, spawning-capable, regressing and regenerating. The sex ratio (F:M) was estimated size-wise and month-wise, Chi-square test was done to test significant difference from an expected sex ratio of 1:1. The size at first sexual maturity (L_{m50}), *i.e,* the TL at which 50% of the species attain sexual maturity, was calculated using logistic equation (King, 2007):

$P = 1/1 + \exp(a+b\ TL)$

where *P* is proportion of mature individuals in a length class, TL is total length, while *a* is intercept and *b* is slope of the logistic equation.

Gonadosomatic index (GSI) was determined for both the sexes separately, using gonadal weight and the total weight of the specimens (De Vlaming *et al*., 1982);

GSI = (Gonad weight / Body weight) × 100

The calculated GSI of *C. hippurus* for different months was plotted to assess the reproductive outline. Significant differences in GSI between months were estimated using the Kruskal-Wallis test followed by Dunn's test.

For fecundity estimation, subsamples were collected from three different regions (anterior, middle and posterior) of the ovary and around 400 to 500 eggs were measured for egg diameter. Absolute fecundity was calculated by multiplying the number of eggs in all subsamples with the total ovary weight (Bagenal and Braum, 1978),

Absolute fecundity = (Number of eggs in the subsample / Weight of the subsample) * Weight of the ovary.

Relative fecundity was estimated as the number of eggs per unit weight (g) of the fish (Bagenal and Braum, 1978).

Results and discussion

The length range of females varied from 25 to 103.5 cm TL (mean 74.74 cm TL) while that of males ranged from 31.7 to 123.5 cm TL (mean 74.01 cm TL). The 60-79 cm length group dominated in both the sexes (Table 1; Fig. 2). The maximum TL reported from Indian waters so far is 185 cm (Benjamin and Kurup, 2012), while the maximum TL reported globally is 184 cm from Panama waters (Guzman *et al*., 2015).

Sex ratio

Overall sex ratio (F:M) estimated was 2.00, with significant deviation from the hypothetical ratio of 1:1 in favour of females (Chi-square = 200.52, p<0.001). Table. 1 shows the sex ratio for different months and size groups. In all size groups, females were dominant. The

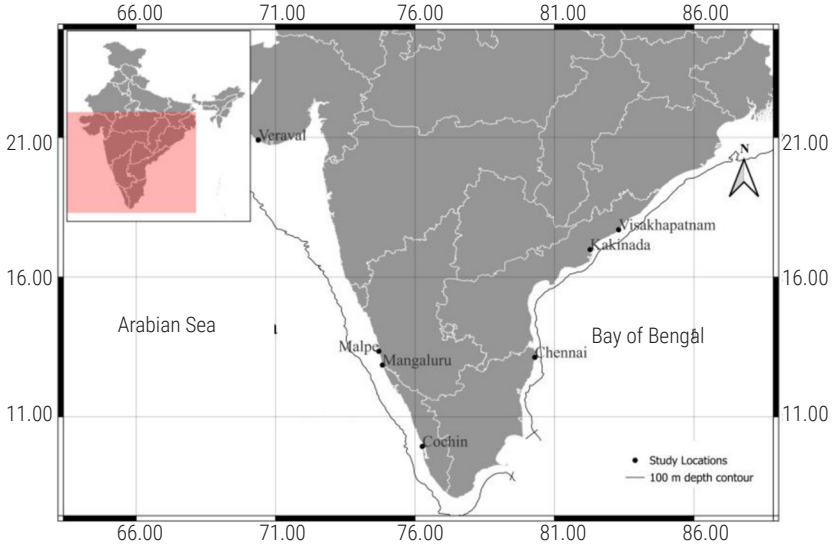

Fig. 1. Map of India showing sampling sites of *C hippurus* along the Indian coast

highest sex ratio (F:M) of 3.44 was observed in May while the lowest ratio of 0.96 was recorded in April. The possibility of low sample counts during these months influencing the sex ratio is high due to the seasonal ban on fishing by mechanised boats. During peak spawning months from July to November, the sex ratio ranged from 1.52 to 2.39, favouring females.

Studies on *C. hippurus* from different parts of the world show female dominance as a common phenomenon (Santos *et al*., 2014; Gatt *et al*., 2015; Molto *et al*., 2020). Sex ratio was in favour of males and ratios of 2:1 and 1.12:1, have been reported in Costa Rica (Campos *et al*., 1993) and western coast of India (Kumar *et al*., 2017) respectively. Previous studies also indicate female dominance in the Arabian Sea (Rajesh *et al*., 2016; Saroj *et al*., 2018). Similar studies have shown that large-sized length groups have male dominance (Zuniga-Flores *et al*., 2011; Ghosh *et al*., 2022) and smaller sizes have female dominance (Kojima, 1966; Santos *et al*., 2014).

The skewed sex ratio favouring females could be attributed to differential growth rates, with males potentially growing faster and becoming more susceptible to fishing pressure at larger sizes. This aligns with observations from other pelagic species, where fishing selectively removes larger, faster-growing individuals (Erzini *et al*., 1997). Furthermore, behavioural differences, such as increased aggression in males may make them more vulnerable to capture by certain fishing gears, further contributing to regional variations in sex ratios (Molto *et al*., 2020).

Table 1. Monthly and length-wise sex ratio in *C. hippurus* from Indian waters

Months	Male	Female	Sex ratio (F/M)	Chi-square
January	62	109	1.76	12.92*
February	84	159	1.89	23.15*
March	107	153	1.43	8.14*
April	25	24	0.96	0.02
May	18	62	3.44	24.20*
June	30	74	2.47	18.62*
July	42	64	1.52	4.57*
August	54	130	2.41	31.39*
September	54	129	2.39	30.74*
October	88	174	1.98	28.23*
November	64	125	1.95	19.69*
December	44	98	2.23	20.54*
Size (TL)				
< 45.0 cm	45	119	2.64	33.39*
45.0-59.9 cm	154	340	2.21	70.03*
60.0-74.9 cm	190	358	1.88	51.50*
75.0-89.9 cm	147	258	1.76	30.42*
≥ 90.0 cm	136	226	1.66	22.38*

*p<0.05

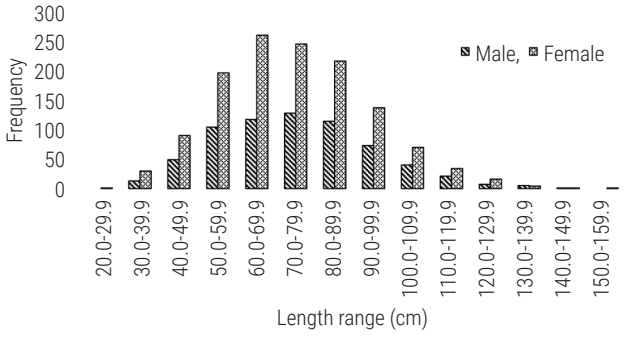

Fig. 2. Length (TL) distribution of male and female *C. hippurus*

Size at first sexual maturity (Lm)

Knowledge on size at first sexual maturity (Lm_{50}) is a vital indicator for formulating a sustainable fisheries management plan and is used for recommending minimum legal size (MLS) for finfish and shellfish species (Mohamed *et al*., 2014). The current study estimated Lm_{50} of *C. hippurus* for females at 62.6 TL and for males at 65.9 cm TL (Fig. 3). The species is known to reach sexual maturity in its first year of life, between the ages of 3 to 7 months and at 64.7 cm TL (as estimated from fork length-FL reported by Molto *et al*., 2020).

The observed Lm_{50} in this study exceeds the current MLS recommendations in India (44.7 cm TL), suggesting that a substantial portion of the catch consists of immature individuals. This discrepancy between maturity size and legal-size limits poses a significant risk to population sustainability, as fish are harvested before they mature and contribute to reproduction (Froese, 2004). Regional variations in Lm_{50} have been well documented, with tropical populations maturing at smaller sizes compared to their temperate counterparts (Wu *et al*., 2001; Moltó *et al*., 2020), possibly due to differences in growth rates, environmental conditions and ecological pressures.

Gonadosomatic index (GSI)

GSI values for females and males are given in Table 2. Average annual GSI for female was 3.21±0.03 and males 1.21±0.21 (Kruskal-Wallis H = 2.0, df =2, p = 0.36). The highest GSI values in females were observed in August, September and January (Kruskal-Wallis H = 13.89, df =11, p = 0.238), and during June and December in males (Kruskal-Wallis H = 9.72, df =11, p = 0.555); there was no significance difference between months. GSI can be treated as a proxy for reproductive activity of the fish. *C. hippurus* are known to breed throughout the year with multiple peaks (Cheung *et al*., 2008). Similarly, in the present study, mature adults were seen throughout the year, in varying numbers. Kumar *et al*. (2017), reported that July and November were the peak spawning months on the west coast of India, while along the Saurashtra coast it was April and December (Saroj *et al*., 2018), and on the Karnataka Coast, it was August and September (Rajesh *et al*., 2016; Assana *et al*., 2021). From the east coast high GSI values were observed in the months of July to December, with highest in September (Ghosh *et al.*, 2022). Studies from other authors showed the species to have different spawning peaks in different geographical locations, June and July in Tunisia (Benseddik *et al*., 2015), March to August and November to January in Mexico (Alejo-Plata *et al*., 2011), February and March in east coast of Taiwan (Wu *et al*., 2001), January to May in Florida (Beardsley, 1967) and March to May in the Gulf of Mexico (Ditty *et al*., 1994). These differences in peak breeding can be credited to the species enhancing its reproductive success by spawning when the environmental parameters are most conducive (Wang, 1979; Massutí and Morales-Nin, 1997; Benseddik *et al*., 2015).

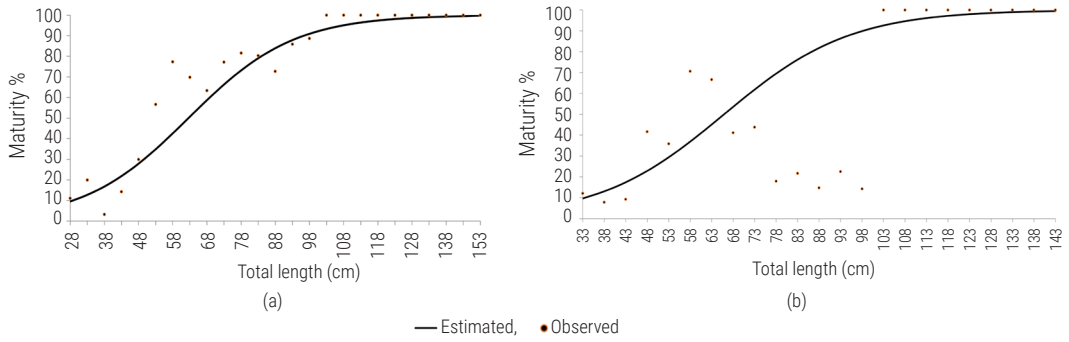

Fig. 3. Size at first sexual maturity (Lm_{50}) of *C. hippurus* from Indian waters (a) Female and (b) Male

Table 2. Monthly occurrence (%) of mature individuals and GSI in *C. hippurus* from Indian waters

Months	Mature females (%)	Mature males (%)	Female GSI (Mean ± SE)	Male GSI (Mean ± SE)
January	49	48	3.69 ± 0.37	1.12 ± 0.12
February	45	43	2.19 ± 0.28	1.04 ± 0.29
March	54	37	3.56 ± 0.62	0.88 ± 0.31
April	63	88	3.26 ± 0.89	1.08 ± 0.40
May	37	39	1.71 ± 0.55	1.04 ± 0.13
June	61	80	2.78 ± 1.30	2.06 ± 0.39
July	78	57	3.15 ± 0.79	0.92 ± 0.15
August	86	56	4.16 ± 0.13	1.33 ± 0.22
September	85	39	4.00 ± 0.24	0.94 ± 0.26
October	73	45	3.15 ± 0.25	1.05 ± 0.27
November	82	63	3.49 ± 0.20	0.90 ± 0.07
December	80	45	3.39 ± 0.51	2.18 ± 1.09

The lack of significant monthly variations in GSI suggests that *C. hippurus* follows a highly flexible reproductive strategy, adapting to local environmental factors such as sea surface temperature and food availability (Oxenford, 1999). This plasticity may explain its wide distribution and success across diverse marine ecosystems. However, climate change induced alterations in oceanographic conditions could disrupt spawning synchrony, underscoring the need for long-term monitoring (Peck *et al*., 2013).

Fecundity and ova diameter

Absolute fecundity of *C. hippurus* ranged from 43,328 to 1,501,818 eggs and increased fecundity with an increase in fish size was observed. Average absolute fecundity was 402,085 eggs per female (SD±297,061). The estimated mean relative fecundity per gram weight of females was 185 eggs (SD±85), with values ranging from 110 to 489 eggs. The species is known to be a highly fecund fish, earlier studies from Indian waters reported average absolute fecundity as 300,878 eggs (Chatterji and Ansari, 1982), 575,391 eggs (Saroj *et al*., 2018), 318,446 eggs (Assana *et al*., 2021) and 434,688 eggs (Ghosh *et al*., 2022). Changes in abiotic, biotic and hereditary factors, and the methodology used to estimate fecundity lead to differences in fecundity values between similar studies (Massutí and Morales-Nin, 1997; Bhuiyan *et al*., 2007; Molto *et al*., 2020).

The high fecundity and batch-spawning strategy of *C. hippurus* contribute to its resilience against fishing pressure. However, this advantage may be counter-balanced by high larval mortality rates in the wild (Houde, 1989). Regional variations in fecundity may be influenced by prey availability, with higher food resources leading to increased reproductive investment (Lambert *et al*., 2003). Future studies should explore the relationship between maternal condition and egg quality to gain deeper insights into recruitment dynamics.

In the present study, egg diameter measurements of *C. hippurus* revealed two peaks at 0.65 and 0.58 mm, with 30.8 and 27.1% of mature female ovaries dominated by eggs of these sizes (Fig. 4). Oocytes ranged from 0.25 to 0.99 mm in ripe ovaries of mature females and multiple peaks indicated the species to be a multiple spawner. Similar findings have previously been reported from Indian waters (Ghosh *et al*., 2022) and other parts of the world (Beardsley, 1967; Shcherbacheu, 1973; Perez *et al*., 1992; Massutí *et al*., 1998; Oxenford, 1999; Alejo-Plata *et al*., 2011), indicating that species are asynchronous batch spawners, with ovary containing varying sizes of oocytes at various maturity stages. Burt *et al*. (1988) and Ditty *et al*. (1994) credit this as a characteristic reproductive strategy in tropical and sub-tropical fishes to increase larval survival in the wild.

In most of the Indian maritime states, recommended MLS (minimum legal size) for *C. hippurus* is 44.7 cm TL (as estimated from FL reported by Mohamed *et al*. (2014); Rohit *et al*. (2016); Muktha *et al*. (2018); Sivadas *et al*., 2019, which is well below the Lm_{50} value of the current study. Hence the results of this study indicate the need for a revision in the available MLS advisories with respect to common dolphinfish landed along the Indian coast.

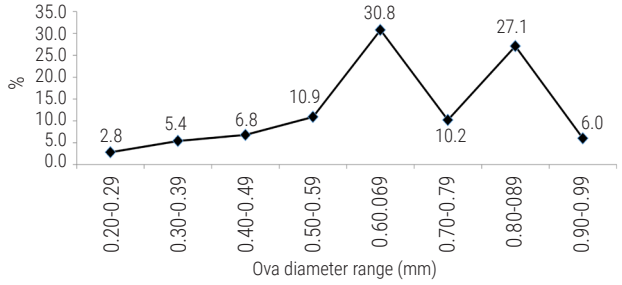

Fig. 4. Egg size (mm) distribution in mature females of *C. hippurus* from Indian waters

This study summarises various reproductive aspects of the common dolphinfish found in Indian waters. Earlier works on the species from Indian waters are region specific and gear specific, whereas this study gives a broader view as the data was collected from different landing centres of the country. The results of the study provide critical inputs for fisheries management of the species for sustainable exploitation. Future studies are essential for understanding the catch dynamics including identifying spawning grounds and larval distribution in Indian waters. This will aid in formulating regulatory measures such as declaring marine protected areas (MPAs) and implementing restrictions on catching brooders and undersised *C. hippurus* for sustainable fisheries management.

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