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Note

Population characteristics unravel occurrence of distinct stocks of yellowfin tuna (*Thunnus albacares*) population in the Indian seas

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Abstract

Fishery and biological observations of yellowfin tuna caught from seas surrounding the Indian mainland and its island territories have indicated the presence of biologically distinct stocks in the region. Those caught around the submerged mounts of Chagos-Laccadive Ridge in the Lakshadweep Sea, off Kerala-Karnataka coast exhibit early maturity, small size at maturity, short lifespan and a close association with sea mounts. In contrast, those caught off other coasts of the mainland, including Andaman waters, exhibit late maturity and larger sizes at maturity indicating a fishery dominated by larger-sized individuals. These findings suggest that the yellowfin tuna associated with the Lakshadweep Sea mounts constitutes a distinct stock, highlighting the necessity for comprehensive genetic, morphometric and population investigations to confirm their stock status.

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Yellowfin tuna (*Thunnus albacares*) constitutes a vital component of the Indian tuna fishery, with annual catches averaging around 18,318 t over the past decade, predominantly harvested by gillnetters, longliners and purse seiners, as well as various small-scale fishing gears such as troll and handlines. They are epipelagic marine species within the family Scombridae and inhabit tropical and subtropical waters of the Pacific, Atlantic and Indian oceans, playing a crucial role as highly migratory top predators that significantly influence marine food webs. Among tropical tuna species, yellowfin tuna holds paramount commercial importance due to its extensive trade potential in both national and international markets, serving as the primary target of oceanic fishing worldwide. However, escalating fishing pressure over recent decades has raised concerns regarding their sustainable utilisation and management (Artetxe-Arrate *et al.,* 2021), as any substantial fluctuations in their abundance could precipitate trophic cascades (Heithaus *et al.,* 2008) and substantially impact the resilience and stability of ocean ecosystems (Kerr *et al.,* 2017).

Available information suggests that the stock structure of the species in the Indian Ocean is highly uncertain, although they are considered as a single discrete stock across the Indian Ocean and managed under the auspices of the Regional Fisheries Management Organisations (RFMO), such as the Indian Ocean Tuna Commission (IOTC), which is central to global food security and underpins multi-billion dollar economic activity in the developed and developing countries of the region. Studies by Durand *et al.* (2005) indicate the occurrence of multiple subpopulations across the western and eastern Indian Ocean. Population assessment and management generally assume these fisheries exploit a single mixed population

within ocean basins. Tagging studies by the Regional Tuna Tagging Project indicate large yellowfin tuna movements, supporting the theory of a single stock for yellowfin tuna in the Indian Ocean (Fuller *et al*., 2023). Durand *et al.* (2005) concluded that genetic differences are low among tuna populations within and between the Pacific and the Indian Ocean; however Ward (2000) suggested that this may be due to lack of sufficient observations and an inadequate sample size. Microsatellite studies by Ely *et al*. (2005) and Dammangodda *et al.* (2008) suggested large genetic heterogeneity in yellowfin tuna around Sri Lanka. Kunal *et al.* (2014), after examining the population structure of yellowfin tuna using sequence analysis of mitochondrial DNA from seven geographically distinct locations along the Indian coast, reported three genetically heterogeneous groups of yellowfin tuna in Indian waters.

Earlier studies have shown that the yellowfin tuna population comprises several sub-populations or stocks across the Indian Ocean (Chow and Takeyama, 2000), highlighting the importance of understanding population variations and stock structure for successful management and conservation of the resource and fisheries. Yellowfin tuna has been extensively studied worldwide, with investigations in to genetic variation in the species from the Pacific and Indian Oceans spanning over the past 50 years (Suzuki, 1962). Milner *et al.* (1963) noted that most of these local races exhibit distinct morpho-meristic characteristics. Diaz-Jaimes and Uribe-Acolocer (2006) utilised several molecular markers, including microsatellite loci, to describe differences in tropical Pacific yellowfin populations, north and south of the equator. However, to date, population genetics alone cannot conclusively prove these assumptions. Kunal *et al.* (2014) suggested that such controversies necessitate detailed investigations along the Indian Ocean at both mtDNA and nuclear DNA levels. Identifying life history traits and stock structure is crucial for ascertaining species resilience and understanding their response to exploitation. This article unveils the existence of two biologically distinct stocks of yellowfin tuna within the Indian exclusive economic zone (EEZ) delineated by their unique population characteristics.

Fishery, biology and population characteristics of yellowfin tuna along the Indian coast, including Island territories, were meticulously monitored during the period 2008-2019, with specific attention given to those caught around the main Lakshadweep islands and sea mounts of Chagos-Laccadive ridge and landed by fishing boats operated from mainland India as well as from Lakshadweep islands (Fig. 1). Data on effort and catch were collected and detailed studies on their biology were conducted. National fishery data from the ICAR-Central Marine Fisheries Research Institute (ICAR-CMFRI), Kochi, for the mainland coast, along with catch statistics obtained from the Departments of Fisheries, UTs of Lakshadweep and Andaman and Nicobar (A&N) islands, were also utilised for analyses. Details on the fishery and biology of the species landed along the A&N islands were also monitored during the same period. Fishing locations were documented from fishers' logbooks or by inquiries, while the length composition of the species landed by major gears were obtained through field samplings. Various aspects of the species biology, including size characteristics in the landing, growth and reproductive biology such as gonadal development and maturity, were examined following methodologies described by Schreck and Moyle (1990). Growth parameters were estimated through modal progression analysis (Pauly, 1980; Pauly and Morgan, 1987) using Electronic Length Frequency Analysis (ELEFAN I) (Gayanilo *et al.,* 2005), with growth described using the von Bertalanffy growth equation (VBGF) (von Bertalanffy, 1938). Length-at-age was validated using hard part inscriptions as outlined by Brothers (1987) and Abdussamad *et al.* (2019). Biological details of 1,867 fishes were analysed for deriving population characteristics, with the length at maturity (Lm_{50}), defined as the length at which 50% of the female yellowfin tuna are classified as mature, determined using a logistic curve considering fishes with ovaries at stages IV and V as mature. Based on the distinctness of population characteristics of the species, they are categorised as "Laccadive sea mount yellowfin" for those caught around the submerged mounts of Chagos-Laccadive Ridge in the Lakshadweep Sea and "Indian EEZ open water yellowfin" for those caught from other areas including Andaman waters for ease of representation in the study.

Yellowfin tuna constituted year-round fishery in Indian waters, including its island areas, with the fishery along the mainland coast primarily composed of relatively larger fishes ranging in size from 42 to 185 cm fork length (FL), with a mean size of 84.4 cm (Fig. 2) and major modes at 80 and 94 cm. Conversely, tuna caught

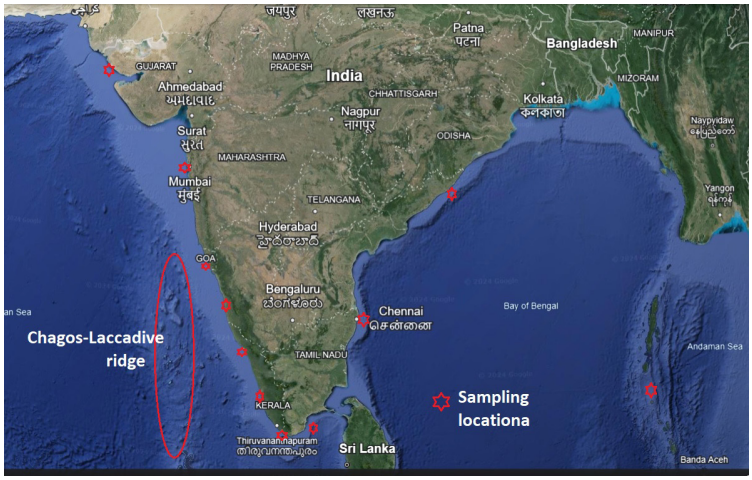

Fig. 1. Data collection sites of the present study

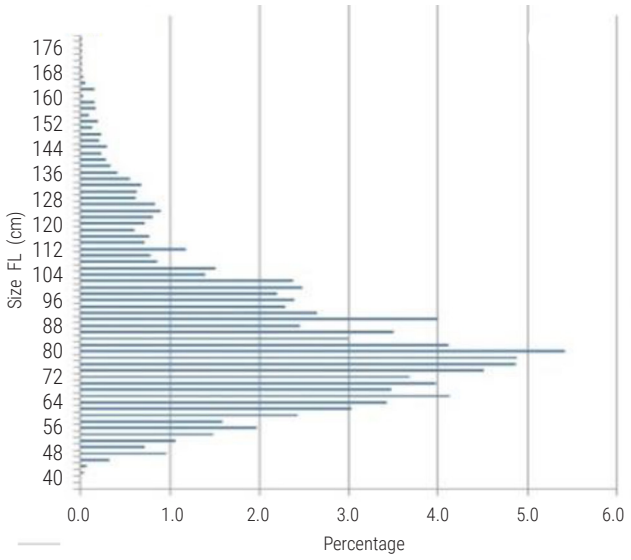

Fig. 2. Size composition of yellowfin tuna caught from Indian EEZ, other than Lakshadweep waters

from seamounts of the Chagos-Laccadive ridges in the Indian EEZ were relatively smaller, measuring 24-125 cm FL with a mean size of 64.2 cm and modes at 50 and 64 cm (Fig. 3). Bineesh *et al.* (2014) provided a comprehensive overview of seamount fisheries, which included an examination of yellowfin tuna fisheries and their seasonal abundance patterns. This study serves as a fundamental reference for understanding the yellowfin tuna fishery within seamount ecosystems. Pillai and Ganga (2008) reported that the size group of yellowfin tuna from the Indian EEZ, typically ranges between 70 and 154 cmFL, consistent with the present observation. Additionally, Rohit and Ram Mohan (2009) noted that the fork length of *T. albacares* ranged from 30 to 190 cm, with a mode of 130 cm,

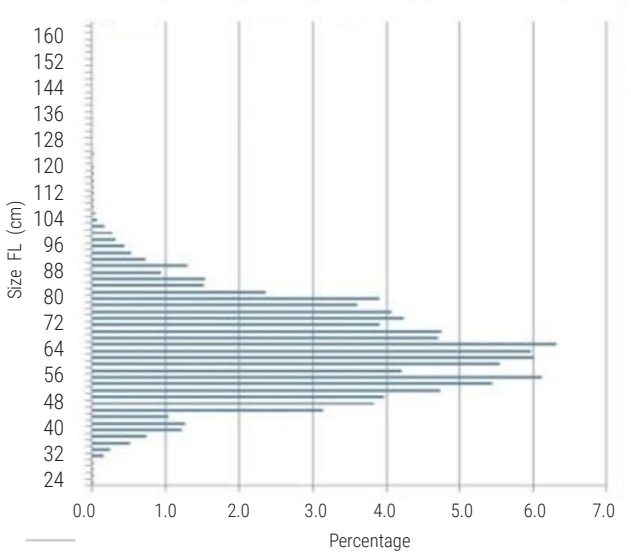

Fig. 3. Size composition of yellowfin tuna caught from seamounts of Chagos-Laccadive ridge, by mainland fishing boats

specifically along the east coast of India. Also Pillai *et al.* (1993) reported a length range of 32-128 cm for yellowfin tuna, while John and Sudarshan (1993) recorded a length range of 60-180 cm for the species from the Indian EEZ. Despite being in an oceanic island area, catches from around the Lakshdweep islands and its adjacent submerged seamounts were supported by smaller fishes.

Samples analysed in the study included both immature and mature fishes. Among the adult population, representation of males and females was nearly equal throughout the study period. Sexual maturity and spawning activities were monitored by evaluating the condition of the gonads of the species in the catch. Gonadal maturity was determined based on factors such as size, external morphology and colouration of the gonad. Fish at all stages of gonadal development were observed throughout the year in the catch, indicating year-round spawning in the species, with a peak occurring from August to January. Yellowfin tuna, similar to other tropical tunas, is oviparous, with their gonads containing multiple batches of oocytes. In the present study, fish with ripe gonads were observed from 86 cm FL onwards for specimens collected from seas around the Indian coast, except in those caught from sea mounts of Laccadive ridge areas. Individuals with spent ovaries were noted in the population from 90 cm FL, with 50% maturity (Lm_{50}) observed at 93.2 cm FL (Fig. 4). This finding aligns with earlier reports suggesting a maturity size range between 75 and 114 cm FL (Wild, 1994; Kailola *et al.,* 1993; Mooney-Seus and Stone, 1997; Rohit and Ram Mohan, 2009; Artetxe-Arrate *et al.,* 2021). In the western Indian Ocean, Lm_{50} values for yellowfin tuna were estimated at 75 cm to 102 cm FL (Zudaire *et al.,* 2013). Similarly, in the eastern and west-central Indian Ocean, estimated Lm_{50} values were higher, ranging from 109 to 114 cm for female yellowfin tuna and 104.9 to 120 cm for males (Nootmorn *et al.,* 2005; Zhu *et al.,* 2008). However, in contrast, yellowfin tuna caught from the Laccadive seamount region showed full gonadal maturity from a much smaller size of 53 cm FL onwards. Individuals with spent ovaries were observed in the catch at 55 cm FL, with 50% maturity observed at 57.76 cm FL (Fig. 5). Some earlier reports from the Philippines and the Central American coast also indicated maturity in yellowfin tunas at smaller sizes ranging from 50 to 60 cm FL (Collette and Nauen, 1983).

The age corresponding to size at maturity for yellowfin tuna collected from the Indian coast other than the Laccadive seamount

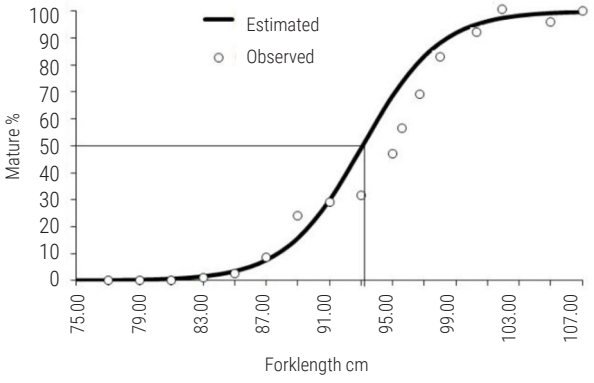

Fig. 4. Logistic curve, estimating size at maturity of yellowfin tuna (females) caught from Indian EEZ

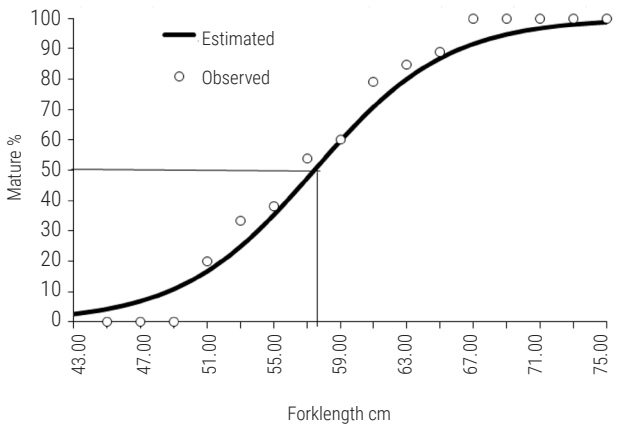

Fig. 5. Logistic curve, estimating size at maturity of yellowfin tuna (females) caught from seamounts of Chagos-Laccadive ridges.

limit is notably higher, exceeding 2.23 years (Fig. 6). This aligns with the reported age at maturity for yellowfin tuna from the Atlantic and Pacific oceans, which also exceeds two years (Kailola *et al.,* 1993; Wild, 1994; Mooney-Seus and Stone, 1997). Age estimates derived from the von Bertalanffy growth equation and hard part investigations indicate that yellowfin tunas collected from the seamounts of the Lakshadweep region mature at a younger age of approximately 1.41 years (Fig. 7). This finding corresponds with estimates of age at maturity ranging from 12 to 15 months for the species from the Philippines and Central America (Collette and Nauen, 1983). The significant differences ($p<0.01$) in the L_{m50} values of yellowfin tuna from the seamounts of the Laccadive ridges compared to those from the waters along the Indian mainland suggest the presence of distinct biological stocks in Indian waters. A key finding of the present study is the absence of any maturing or mature yellowfin tuna specimens below 70 cm FL in landings of Indian EEZ open water yellowfin, whereas yellowfin tunas caught from the seamounts of the Laccadive ridges showed signs of maturity from sizes as small as 50 cm FL. Additionally, it is inferred that the age of the largest yellowfin tuna (T_{max}) observed from the Indian EEZ openwater yellowfin is 8 years, whereas, for yellowfin tunas from the seamounts of the Laccadive ridges, it is 3.96 years (Fig. 6 and 7). Tagging studies using pop-up satellite tags to track the migratory paths of yellowfin tunas have indicated that the movement of yellowfins from the Lakshadweep Island region is predominantly restricted within the southern parts of Indian EEZ, and they do not seem to undertake extensive basin-wide migration (Nimit *et al.,* 2020). These findings suggest that the yellowfin tuna population associated with the Laccadive seamounts, primarily exhibits migratory ranges confined to the southern regions of the Indian EEZ.

The study presents a detailed comparactive analysis of catch and biological characteristics of yellowfin tuna caught along the mainland coast and those from seamounts, with emphasis on the Laccadive sea mounts. The fishery is year-round, with distinct size compositions observed between the Indian EEZ open water yellowfin tunas and the Laccadive seamount yellowfins. Notably, the presence of distinct biological stocks is evident, with differences in size and age at maturity, size composition in the population and migratory patterns between yellowfins from both regions. Furthermore, age at maturity estimates vary significantly, with implications for conservation and management strategies. Thus significant disparity in the biological and population characteristics of yellowfin tuna associating with the seamounts of Chagos-Laccadive ridges compared to the Indian EEZ open waters, along with the reported notable differences in migratory patterns, reaffirms the hypothesis that yellowfin tuna in Indian waters is composed of distinct stocks. This finding underscores the necessity for comprehensive investigations into the stock structure analysis of this commercially and ecologically significant oceanic species. Such investigations should incorporate detailed examinations at both mitochondrial DNA (mtDNA) and nuclear DNA levels. The observed differences in size may be attributed to variances in habitat preferences and feeding patterns between the two populations, emphasising the necessity for additional research. Furthermore, the findings of the study highlights the importance of developing specific and tailored stock management programmes for each stock to ensure their conservation and sustainable utilisation.

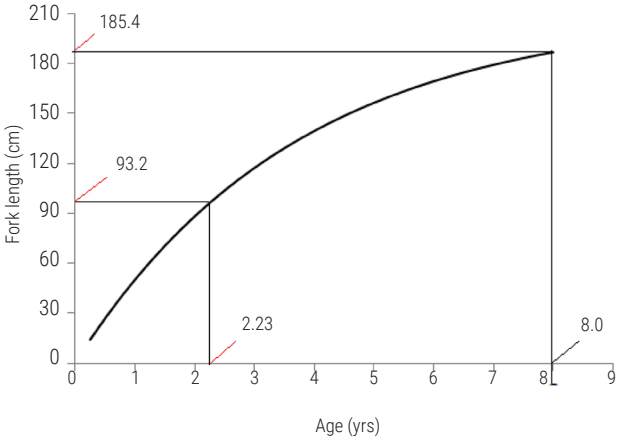

Fig. 6. Age and size characteristics of yellowfin tuna from Indian EEZ

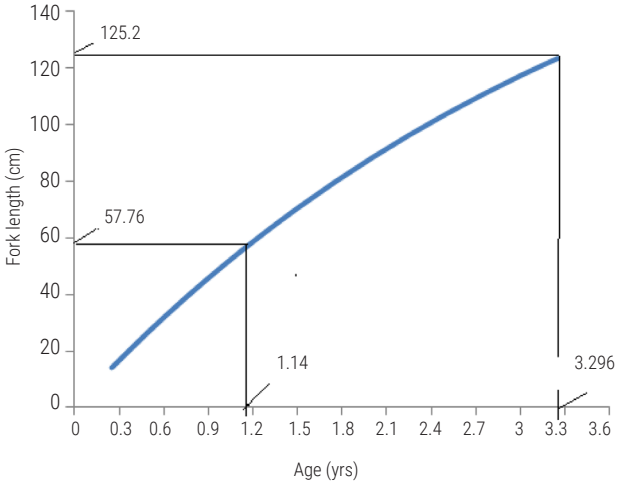

Fig. 7. Age and size characteristics of yellowfin tuna from seamounts of Chagos-Laccadive ridges

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