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Relationship between fish length and otolith dimensions of Yellow striped goatfish, *Upeneus vittatus* (Forsskal, 1775) along the Indian coast

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Otoliths are widely used to estimate the age and growth of fishes and to identify fish species. This information plays a vital role in fisheries management and population dynamics studies. The information about fish length and otolith dimensions relationship of *Upeneus vittatus* is lacking from the Indian water. In this study, a total of 237 numbers of individuals were collected from October 2018 to March 2019 and left otolith was studied since there were no significant differences between right and left otoliths. The relationships between total length and otolith dimensions were estimated by linear regression analysis and found a strong positive correlation. The maximum correlation was found between fish length and otolith length for Mumbai populations ($R^2 = 0.9342$). In contrast, Kakinada populations had the maximum correlation between fish length and otolith width ($R^2 = 0.8957$), and Puri populations had the maximum correlation between fish length and otolith weight ($R^2 = 0.9101$). Present study found a strong positive correlation between fish length and otolith dimensions of *U. vittatus*. This finding provides new insights into the field and can be used for the growth study, fish population assessment, and fisheries management.

[**Keywords**: Assessment, Correlation, Linear regression, Management, Otoliths dimensions]

Introduction

Goatfishes are a commercially important group of fishes belonging to the family Mullidae. They are distributed in the tropical and subtropical regions of the Indo-Pacific and Western Atlantic Oceans. They are also distributed along both the coasts of India (East and West coast) and contribute significantly to the country's demersal fishery resource. Off the coast of Visakhapatnam, it was reported that the peak spawning season of *U. vittatus* was during July and October[1], although it was observed to occur from February to October, indicating a prolonged spawning season. *U. vittatus* feeds primarily on small crustaceans, mainly shrimps and crabs (59.49 %), and teleostean fishes (14.51 %), making up the bulk of the diet where as bivalve and mollusks accounting for 13.51 % of the gut content[2]. Though these species constitute one of India's essential food fishes of considerable regional importance, they have drawn very little attention from fishery scientists apart from the systematic account of Francis Day[3] and a few other works on the biology of this species. Detailed accounts of this species' systematic biology and fishery from the Indian region are scanty.

Otoliths are composed of calcium carbonate structure ($CaCO_3$), and it acts as hearing and balancing organs[4]. An individual fish species' permanent life history records can be obtained from the otolith. They also provide information about fishes' size, age, ontogeny, and growth[5]. In bony fishes, the sagittal otolith is the most massive pair that the fishes have in their saccule of the inner ear[6]. Otoliths shape is highly species-specific, and it varies widely among fish species and families[6,7]. The composition of fish otoliths is proving helpful to fisheries scientists. Fishery biologists use Sagittae in different aspects of biological studies due to their distinct growth rings and large size[8,9]. The otolith is one of the most reliable tools for studying the fish population's age structure and growth rates. This information plays an essential role in fisheries management to achieve the sustainable yield, avoid recruitment failure, rebuild overfished stocks, and conservation of threatened and endangered species.

Otolith biochemical analysis is a technique used in fisheries biology and fisheries management to find the natal origin of fish, characterize movements, and delineate stocks and feeding ecology[10]. The use of fish otolith for fisheries management is not restricted, but it has full application in archaeology, paleontology, and marine biology[7]. The relationships between fish length and otolith dimensions became a common practice in the middle of the twentieth century when otoliths were used in retrieving the fish size from their otolith size[11-14].

A simple linear regression can explain the relationship between the fish length and otolith dimensions[6], but it is yet to investigate for *U. vittatus* from the Indian waters. Previously only otolith morphology work has been carried out. Hence, the present study aimed to determine the relationship between fish length and otolith dimensions of *U. vittatus* along the Indian coast. The outcome of these findings is expected to serve as baseline data for growth and age study, sustainable management of fisheries and provide valuable information for future research on fish population dynamics along the Indian coast.

Materials and Methods

Sampling

A total of 237 samples were collected randomly from three landing centers (Figs. 1, 2), *i.e.*, 80 from Mumbai (18°54’ N, 72°49’ E), 90 from Kakinada (16°57’ N, 82°15’ E) and 67 from Puri (19°81’ N, 85°83’ E) during October 2018 to March 2019 (Table 1). The specimens were transported to the lab and washed properly. The total length (TL cm) was initially measured for each specimen nearest to 0.1 mm. The left sagittal otolith was precisely removed from each fish specimen, cleaned to remove adhering tissue, and stored in dried plastic vials for further examination. The broken otoliths were removed. Otolith weight was measured nearest to 0.0001 g using an electronic balance.

Image capturing and morphometric data extraction

All the left sagittal otoliths were examined and photographed using a Stereo zoom microscope with a digital camera (Nikon SMZ1000) at 4X magnification (Fig. 3). Sagitta was positioned with the concave side

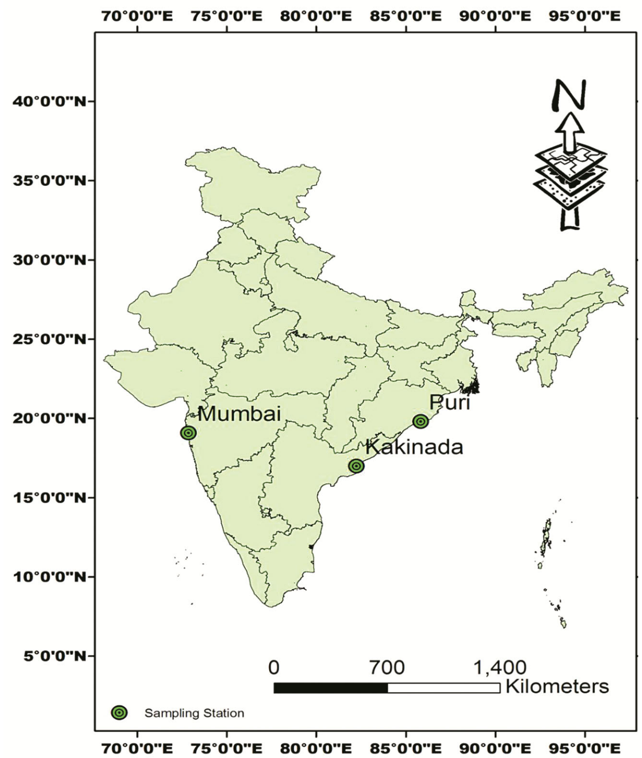

Fig. 1 — Map showing the sampling locations of *U. vittatus* along the Indian coast.

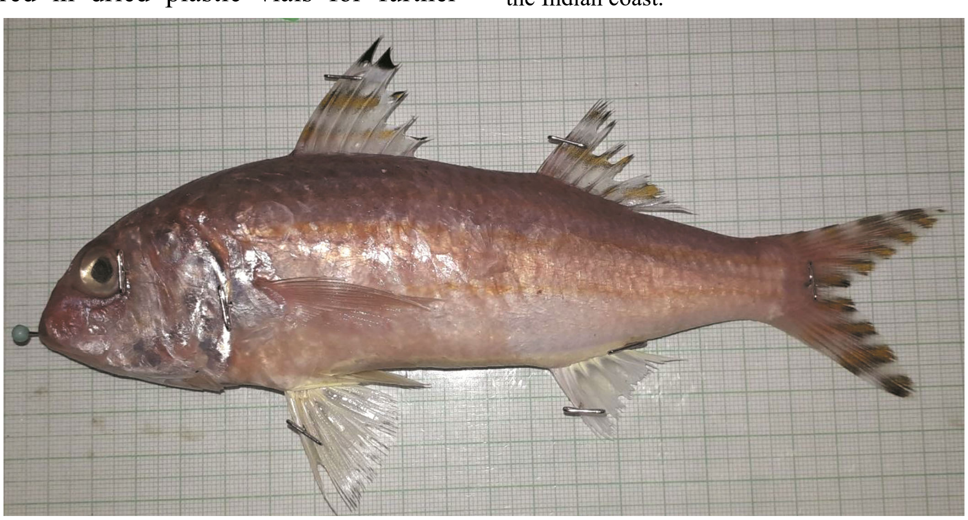

Fig. 2 — Photograph of *U. vittatus*

Table 1 — Fish length and otolith dimensions measurement of *U. vittatus* from the Indian coast

Sampling Station	Sampling location	N	Measurement	Min	Max	Mean	S. D	SE
Mumbai	18°54' N, 72°49' E	80	Total length (cm)	10.95	21.44	15.62	1.91	0.21
			Otolith length (cm)	0.314	0.5962	0.399	0.0378	0.004
			Otolith width (cm)	0.112	0.398	0.251	0.037	0.004
			Otolith weight (g)	0.0029	0.0089	0.0058	0.0012	0.00013
Kakinada	16°57' N, 82°15' E	90	Total length (cm)	11.67	17.52	13.92	1.07	0.11
			Otolith length (cm)	0.334	0.487	0.394	0.025	0.0026
			Otolith width (cm)	0.212	0.304	0.248	0.014	0.0015
			Otolith weight (g)	0.0031	0.0079	0.0055	0.00088	0.000094
Puri	19°81' N, 85°83' E	67	Total length (cm)	11.87	16.59	14.00	0.98	0.12
			Otolith length (cm)	0.327	0.409	0.359	0.0192	0.0023
			Otolith width (cm)	0.208	0.272	0.235	0.015	0.0019
			Otolith weight (g)	0.002	0.0099	0.0045	0.0010	0.00013
Total		237						

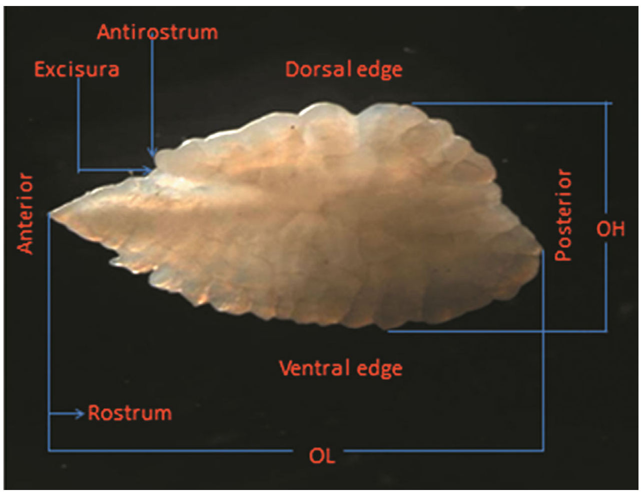

Fig. 3 — Otolith morphometry of *U. vittatus* used to study relationship with fish length. (Note: OL: Otolith Length, OH: Otolith width)

up and the rostrum pointing to the left before taking the image. Otolith dimensions (length - the maximum distance between the anterior and posterior points, and width - the most considerable distance between the ventral and dorsal edges) were measured using Image-Pro Premier 9.1 software. This software is significantly helpful and has been used widely in extracting landmark distance data from digital images of objects.

The significant differences between the right and left otolith were checked using the ANOVA test. The relationships between the fish length and otolith dimensions (otolith length, otolith width) were estimated using the linear regression model, $y = a + bx$; where, y: otolith length and otolith width, x: fish length, a: intercept value, and b: coefficient value. The fish length and otolith weight relationship were determined by using a regression model, $TL = a\ (OW)\ b$; where, OW is otolith weight. Microsoft Excel software (version 2019) was used to determine the relationships between fish length and otolith dimensions. Descriptive statistics were carried out by using Statistica 12 software package.

Results

In this study, a total of 237 samples were collected randomly from three landing centers. The results of the descriptive statistics are given in Table 1. The findings revealed that the left and right otoliths of *U. vittatus* are not significantly different in size from one another. For the Mumbai population, the total length, otolith length, otolith width and otolith weight ranged between 10.45 – 21.44 cm, 0.314 – 0.5962 cm, 0.112 – 0.398 cm and 0.0029 – 0.0089 gm, respectively (Table 1). For the Kakinada population, the total length, otolith length, otolith width, and otolith weight were ranged between 11.67 – 17.52 cm, 0.334 – 0.487 cm, 0.212 – 0.304 cm, and 0.0031 – 0.0075 gm, respectively (Table 1). Similarly, for Puri population the total length, otolith length, otolith width and otolith weight were ranged between 11.87 – 16.59 cm, 0.327 – 0.409 cm, 0.208 – 0.272 cm and 0.002 – 0.0099 gm, respectively (Table 1). Puri population had the highest correlation between fish length and otolith weight (R^2 = 0.9101), followed by Kakinada and Mumbai populations (Fig. 4a, d, g). The maximum correlation between fish length and otolith width was observed in the Kakinada population (R^2 = 0.8957), followed by Odisha and Mumbai populations (Fig. 4b, e, h). The maximum correlation between fish length and otolith length was observed in the Mumbai population (R^2 = 0.9306), followed by Odisha and Kakinada populations (Fig. 4c, f, i).

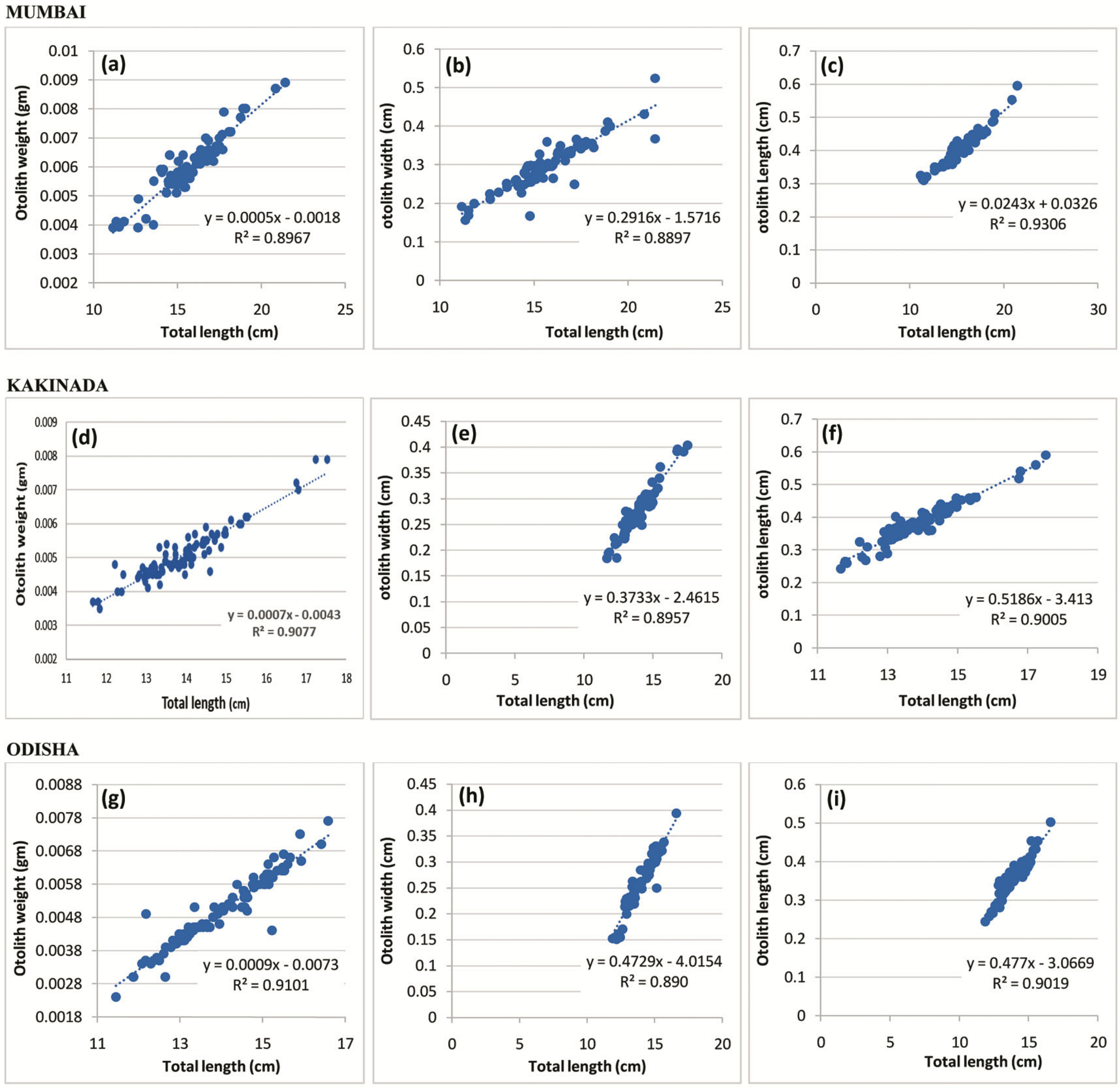

Fig. 4 — Relationship between (a – c: Mumbai): a) total length and otolith weight, b) total length and otolith width and c) total length and otolith length; (d – f: Kakinada): d) total length and otolith weight, e) total length and otolith width and f) total length and otolith length; (g – i: Odisha): g) total length and otolith weight, h) total length and otolith width and i) total length and otolith length; of *U. vittatus*

Discussion

Otoliths are generally used to determine the age of fishes and for taxonomical identification. This information is essential for stock identification[15], population management, archaeological research, and predator-prey relationship studies[6]. This species plays a significant role in the food chain because of its small size and attractive shimmering color. It has got commercial importance in the local market. Despite immense ecological and economic importance, this species' ecology, biology, and population structure have not been well investigated along the Indian coast. The same species inhabited in different regions will have different growth rates. Such differential growth rate will affect the otolith morphology[16]. This different growth rate of otolith is most often related to environmental parameters (water temperature, salinity) and the species' diet[17,18].

The present study shows that otolith length correlates more positively with fish length than width and weight. This indicates that the fish size information can be obtained if otolith length is known. Similar results are obtained from Australia on *S. lemuru*[19]. There is a strong correlation between the fish and otolith lengths, possibly due to their association with similar metabolic processes[20]. The fish size and otolith dimensions relationships can differ based on several factors in the commercial catch, including changes in sex or age composition, mesh size regulations, fishing gear modification strategies, and different analytical methods[21,22]. The maximum correlation between fish length and otolith weight was obtained from the Odisha population. Similarly, the highest otolith weight was also obtained from the Odisha population (0.0099 gm). Otolith development mainly occurs under two conditions; genetic conditions regulate the otolith formation and environmental conditions; carbon saturated water temperature regulates the quantity of material deposited in otolith[17]. This may be due to weaker winds blowing over the Bay of Bengal, making slow oceanic circulation more than the Arabian Sea, where oceanic circulation is very high due to strong winds and making the water move down and cooler[23]. The maximum width of the otolith was observed in the Mumbai population. The growth of the otolith depends on habitat, food availability, fish species, and physio-chemical parameters of the environment where they live[14,24]. The productivity of the Arabian Sea is higher than that of the Bay of Bengal because upwelling systems bring colder and nutrient-rich waters[25]. It is possible that the high nutrient content in the Arabian Sea could be contributing to the growth of otoliths in fish populations of Mumbai waters, potentially resulting in larger and healthier fish. Nutrient-rich waters can support the growth of phytoplankton and zooplankton, which are essential food sources for many fish species. When fish consume these organisms, they can absorb the nutrients and minerals needed for healthy growth, including calcium, which is a key component of otoliths.

However, scientific research needs to confirm whether there is a direct correlation between nutrient content, food availability, and otolith growth in this location. Previous studies mainly focused on the otolith morphology of *U. vittatus*[26], but no study has been done for fish length and otolith dimension relationships. This present study provides additional information about the relationships between fish length and otolith dimensions of *U. vittatus* along the Indian coast. Using more than one equation to calculate (total length-otolith width and total length-otolith length) relationships is always advisable.

Conclusion

The present investigation revealed a strong positive correlation between fish length and otolith dimensions of *U. vittatus* along the Indian coast. Hence, the growth of otoliths can be used as an indicator of the growth of the fish itself. The findings of the present study could also help fishery managers to develop effective conservation and management strategies that balance the needs of the fishery with the long-term sustainability of *U. vittatus* fisheries along the Indian coast. More comprehensive studies need to be conducted to understand the fishes' biology before further inferences could be made on comparisons among these various sites.

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Conflict of Interest

The authors declare there is no conflict of interest for the manuscript.

Author Contributions

The first author (SN) has done the overall research work, including sample collection, otolith measurement, data collection, analysis and interpretation. Other co-authors (SB, AKJ, KR & VP) helped in conceptualization, overall monitoring, guidance, data analysis and interpretation, writing, and manuscript editing.

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