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Research Article

Insights into the biometry and life-history traits of Goldband goatfish (*Upeneus moluccensis*) for sustainable management in the northwest coast of India

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The sex ratio, biometric analysis, and life-history traits of 606 individuals (10.5 – 22.5 cm TL) of *Upeneus moluccensis* (Bleeker, 1855) were studied from September 2022 to August 2023 along Veraval fishing harbour, Gujarat, particularly in a geographic region where such information was previously scarce. The mean sex ratio (1F:1.03M) was found to be insignificant ($p > 0.05$; χ^2 test). Morphometric characteristics indicated significant ($p < 0.05$, univariate ANOVA) disparity between male and female specimens. Morphometric analyses and indices suggested a low coefficient of variation (< 16 %) and a restricted distribution of the species. Standard length and fork length showed a high growth rate and maximum correlation among different morphometric features for both sexes. The *b* value of length-weight relationships revealed hyperallometric growth ($b > 3$; $p < 0.05$, *t*-test), indicating that the fish become heavier as they grow. The near unity relative condition factor ($K_n \approx 1$) and higher Fulton condition factor ($K_F > 1.20$) for both males and females suggested favourable growth conditions. Body condition, reflected by a higher percentage of lean fish, suggested October to December as the peak spawning period. Size-based estimates recommend a harvest size limit range of 13.3 – 16.3 cm for the species. The detailed biometric and life-history information provided in this study can facilitate conservation, management, and sustainable utilisation of this species in the study area.

[**Keywords**: Biometric, Corporeal, Hyperallometric, Mega-spawners, *Upeneus moluccensis*]

Introduction

Biometrics involves the quantitative evaluation of fish using linear measurements, such as total or standard length, which are key for understanding taxonomy and determining various population parameters. Length-length relationships, commonly used in biometric studies, are instrumental in stock assessment as they highlight regional variability, thereby distinguishing between homogeneous and heterogeneous populations. Length-weight relationships and condition factor offer valuable insights into the health status of fish, supporting sustainable fisheries management[1]. Among the many families studied for fishery biometrics, the family Mullidae holds particular interest due to its ecological and commercial significance. The family comprises six genera and 107 valid species globally[2], of which 20 species from three genera – *Mulloidichthys*, *Parupeneus* and *Upeneus* have been confirmed in Indian waters[3,4]. The total goatfish landings in 2023 were 15,604 tonnes, contributing 0.44 % to the total marine fish landings of the country[5]. *Upeneus moluccensis* (Bleeker, 1855), commonly known as Goldband goatfish and referred to as "*Piri Patti*" in Gujarati, is a small-sized, demersal, fast-swimming species. It exhibits schooling behaviour and inhabits muddy or sandy substratum at depths of 20 – 130 m[ref. 6]. The species is widely distributed in the Indian and Pacific Oceans and has invaded the eastern Mediterranean Sea. The species feeds on small teleosts and benthic crustaceans, with peak spawning occurring between June and September[7]. It is sold fresh in local markets and used in the surimi industry for export[8].

Previous studies on *U. moluccensis* have primarily focused on length-weight relationships, taxonomy, and stock characterisation[3,6,9-17]. Henceforth, there are no detailed investigations on biometric parameters from the study area. Hence, this study aimed to elucidate information on sex ratio, size-frequency distribution, morphometric and meristic characteristics, Length-Length Relationships (LLRs), Weight-Weight Relationships (WWRs), and various condition factors (relative, Fulton and allometric condition factors) of Goldband goatfish from the northwest coast of India, as an imperative means to aid fishery managers in framing proper conservation strategies for sustainable utilisation.

Materials and Methods

A total of 606 samples of *Upeneus moluccensis* (10.5 – 22.5 cm TL, 11.67 – 143.53 g TW) were procured on a fortnightly basis from the bycatch landings of single-day trawlers operating along the Veraval fishing harbour (20°54′ N, 70°22′ E), Gujarat, northwest coast of India, from September 2022 to August 2023 except in fishing ban period during June – July 2023 declared by the Department of Fisheries, Government of India. The specimens were packed in ice and immediately transported to the laboratory of the Department of Fisheries Resource Management, College of Fisheries Science, Veraval, for further analysis. The Total Length (TL) and Total Weight (TW) of each individual were measured using a Vernier Calliper (accuracy 0.1 cm) and an electronic weighing balance (accuracy 0.01 g), respectively. After that, the fish was dissected, and the gastrointestinal tract, pyloric caeca, liver, gas bladder, and gonads were removed, and the Eviscerated Weight (EW) was recorded.

The sex ratio was evaluated by different months and size groups, with the ratio of females to males tested using a chi-square test (χ^2). The length-frequency distribution was constructed using 1.0 cm class intervals of total length for both sexes. Morphometric characters such as Total Length (TL), Standard Length (SL), Fork Length (FL), Pre-Dorsal Length 1 (PDL1), Pre-Dorsal Length 2 (PDL2), Pre-Pectoral Length (PPL), Pre-Ventral Length (PVL), Pre-Anal Length (PAL), Trunk Length (TkL), Head Length (HL), Snout Length (SnL) Eye Diameter (ED), Inter-Orbital Distance (IOD), Post-Orbital Length (POL), Upper Jaw Length (UJL), Lower Jaw Length (LJL), Dorsal Fin Base Length 1 (DFBL1), Dorsal Fin Base Length 2 (DFBL2), Anal Fin Base Length (AFBL), Pectoral Fin Length (PFL), Ventral Fin Length (VFL), Caudal Fin Length (CFL), Caudal Fin Depth (CFD), Caudal Peduncle Length (CPL), Caudal Peduncle Depth (CPD), Ventral to Anal Length (VAL), Body Depth at Anal Opening (BDAO), Body Depth Maximum (BDM), body girth through mid-eye (G1), body girth through gill-cover (G2) and maximum body girth (G3) were recorded separately for each sex to the nearest 0.1 cm using a Vernier Calliper and measuring tape following standard procedures[18,19]. A univariate Analysis of Variance (ANOVA) was conducted to test the significant differences in morphometric variables between male and female fishes[20]. Statistical estimates, including range, mean, standard deviation, Coefficient of Variation (CV), and Index of Morphometric ($IM = morphometric\ character \times 100 \times TL/HL^{-1}$) were calculated[21]. Various morphometric characters were grouped into three classes – genetically controlled (< 10 %), intermediate (10 – 15 %), and environmentally controlled (> 15 %) – based on range differences[22]. The fin formula was recorded following the meristic counts.

The linear relationships between different morphometric measurements were established using the regression equation ($Y = a + bX$). The correlation coefficient (r) was evaluated to assess the degree of correlation between the morphometric characters. Based on the r-value, different morphometric variables were grouped into three classes: high (> 0.90), good (0.75 to 0.90), and moderate (0.50 to 0.75) correlation. The Length-Weight Relationships (LWRs) were fitted separately for each sex using the least square method ($TW = a \times TL^b$)[23]. Extreme outliers were removed by constructing a log-log plot of length-weight pairs. The r^2 and 95 % confidence interval values of a and b were calculated to assess estimation precision. Significant differences in the b values between males and females were tested using One-way Analysis of Covariance (ANCOVA). A student's t-test (t_s) was performed to test the null hypothesis of isometric growth ($b = 3$): $t_s = (b–3)/S_b$. The Total Weight (TW) and Eviscerated Weight (EW) relationships were fitted separately for males, females and pooled data using a linear regression prototype ($EW = a + bTW$). Further, r and 95 % confidence interval values of a and b were analysed.

The month-wise relative condition factor (K_n), Fulton condition factor (K_F), and allometric condition factor (K_A) were determined[24-26]. Based on K_A and intercept (a) value, individuals were grouped into three modified categories: lean ($K_A < a$), fit ($K_A = a$) and plump ($K_A > a$)[27]. Average Relative Weight (W_R) was calculated using the formula $W_R = (TW/TWs) \times 100$[ref. 23]. Where, TW = wet weight and TWs =

predicted standard weight of the same individual ($TWs = aL^b$). The form factor ($a_{3.0}$) was determined for each sex using the equation $a_{3.0} = 10^{\log a - s(b-3)}$, where a and b are the regression parameters of LWRs and s is the regression slope of ln a versus b[ref. 23]. The life-history parameters such as asymptotic length ($L\infty$), asymptotic weight ($W\infty$), size at first sexual maturity (L_m), age at first sexual maturity (t_m), longevity (t_{max}), growth performance index ($Ø'$), natural mortality (M_W), and optimum catchable length (L_{opt}) were analysed using the equations 1 – 8[refs. 28-32]:

$$\log L\infty = 0.044 + (0.9841 \times \log L_{max}) \quad \ldots (1)$$

$$W\infty = a \times L\infty^b \quad \ldots (2)$$

$$\log L_m = (0.8979 \times \log L\infty) - 0.0782 \quad \ldots (3)$$

$$t_m = \left(-\frac{1}{1}\right) \times \ln\left(1 - \frac{L_m}{L\infty}\right) \quad \ldots (4)$$

$$\log t_{max} = (0.9570 \times \log t_m) + 0.5496 \quad \ldots (5)$$

$$Ø' = (\log K) + (2 \times \log L\infty) \quad \ldots (6)$$

$$M_W = 4.899 \times t_{max}^{-0.916} \quad \ldots (7)$$

$$L_{opt} = \left(\frac{3\ L\infty}{3 + \frac{M_W}{K}}\right) \quad \ldots (8)$$

Where, L_{max} = maximum total length recorded in the study, and K = growth coefficient derived as $3/t_{max}$.

Three size-based reference points (P_{mat} – proportion of sexually mature individuals present in catch; P_{opt} – proportion of optimally sized individuals defined as the percentage of fish between $0.9L_{opt}$ and $1.1L_{opt}$; P_{mega} – mega-spawners) were determined for each sex. These reference points aim to maintain prudent exploitation and prevent growth and recruitment overfishing[33-35]. The percentage of each reference point was summarised in equations 9 – 11:

$$P_{mat} = \sum_{L_m}^{L_{max}} P_L \quad \ldots (9)$$

$$P_{opt} = \sum_{0.9L_{opt}}^{1.1L_{opt}} P_L \quad \ldots (10)$$

$$P_{mega} = \sum_{1.1L_{opt}}^{L_{max}} P_L \quad \ldots (11)$$

Where, P_L is the percentage of fish in the catch in the length interval L.

P_{obj} (a composite indicator of population size structure) might be utilised in multi-gear fisheries, where the assumption of trawl-like selectivity is often not realised.

$$P_{obj} = P_{mat} + P_{opt} + P_{mega} \quad \ldots (12)$$

P_{obj} was further interpreted using a decision tree constructed based on a deterministic age-structured population dynamics model[34]. The researchers found that P_{obj} was more closely associated with Spawning Biomass (SB) than any of the size-based indicators (SBIs). They also linked various selectivity patterns in the fishery to a range of P_{obj} values. Once a selectivity pattern based on P_{obj} is established, threshold values of P_{mat}, P_{obj}, and the L_m/L_{opt} ratio are compared with an empirically established reference point to assess whether the stock is above or below the SB reference point (0.4 SB = Target Reference Point (TRP) or 0.25 SB = Limit Reference Point (LRP)), indicating the overfished status of the fishery[33-35].

All statistical analyses and data processing were conducted using IBM-SPSS 21.0, MS-Excel 2021, and PAST 4.03 software. A Wilcoxon signed-rank test was employed to assess the prey-predator status by comparing the W_R with 100[ref. 36]. A 5 % level of significance was set for all the statistical tests.

Results

Sex ratio and size structure

The mean sex ratio of *Upeneus moluccensis* showed no significant difference ($p > 0.05$, χ^2 test) from the ideal ratio (1:1). However, a significant ($p < 0.05$, χ^2 test) predominance of males was recorded in September, and females in January (Table 1). Sex ratio in different size groups indicated that males were dominant ($p < 0.05$, χ^2 test) in the 12 – 14 cm group, while preponderance of females was documented in the large size groups (16 – 18, 18 – 20 and ≥ 20 cm) (Table 1). The size frequency graphs revealed that males were prominent in the 12 – 15 cm size group, while females were dominant in the 16 – 23 cm size group (Fig. 1).

Morphometric and meristic characters

All 31 morphometric variables of *U. moluccensis* examined in the current study exhibited statistically significant differences between sexes ($p < 0.05$, univariate ANOVA). Consequently, separate analyses were conducted for males and females for each morphometric character to facilitate comparisons across various locations. The Coefficient of Variation (CV) ranged from 9.46 % (SL) to 14.12 % (CD) in males and 12.73 % (CPL) to 17.67 % (SnL) in females. The mean values of all morphometric variables and CV were slightly higher in females than in males (Table 2). Based on the range difference in

Table 1 — Statistical estimates of sex ratio (female: male) by months and sizes for *Upeneus moluccensis* from northeastern Arabian Sea (*$p < 0.05$)

Month/Size (Total length, cm)	Number of females	Number of males	Sex ratio	χ^2 (df = 1)	*p*-value
Sept	15	35	1:2.33	8.000	0.0047*
Oct	41	29	1:0.71	2.057	0.1515
Nov	52	39	1:0.75	1.857	0.1730
Dec	27	37	1:1.37	1.563	0.2113
Jan	49	29	1:0.59	5.128	0.0235*
Feb	35	30	1:0.86	0.385	0.5351
Mar	33	41	1:1.24	0.865	0.3524
Apr	16	22	1:1.38	0.947	0.3304
May	17	23	1:1.35	0.900	0.3428
Aug	13	23	1:1.77	2.780	0.0956
Pooled	298	308	1:1.03	0.170	0.6846
10–12	11	08	1:0.73	0.474	0.4913
12–14	77	123	1:1.60	10.580	0.0011*
14–16	123	138	1:1.12	0.862	0.3532
16–18	61	33	1:0.54	8.340	0.0039*
18–20	18	06	1:0.33	6.000	0.0143*
≥ 20	08	0	-	-	-

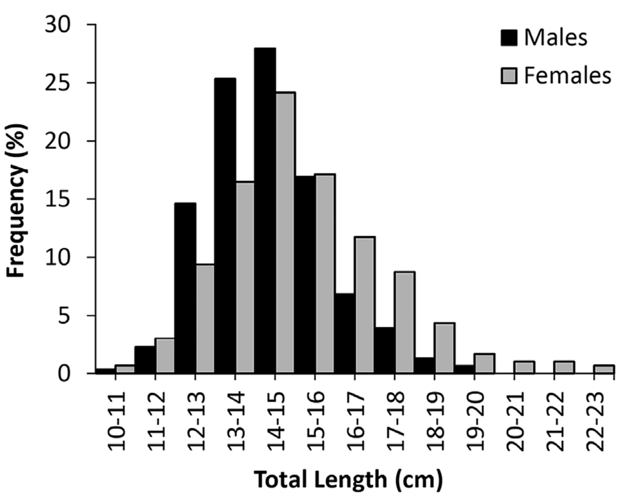

Fig. 1 — Length-frequency distribution of male (n = 308) and female (n = 298) populations of *Upeneus moluccensis* landed along the northeastern Arabian Sea

the index of morphometric (IM), most morphometric variables (22 characters in males and 21 characters in females) were categorised as genetically controlled (range difference < 10 %) (Table 3). The fin formula of *U. moluccensis* in the present investigation could be described as D1: VIII; D2: I, 8 – 9; P: 15 – 18; V: I, 4 – 5; A: I, 6 – 7; gill rakers 21 – 28.

Length-Length Relationships (LLRs)

The linear LLRs of *U. moluccensis* were found to be highly significant ($p < 0.05$, *t*-test) for both males and females. The *b* value of the LLRs indicated a higher growth rate in females than males for most morphometric variables (Table 4). The maximum and minimum growth rates in relation to TL were observed in FL and AFBL, respectively. However, the maximum growth rate in relation to HL was found in post-orbital length (POL), followed by SnL and UJL. The *r* value indicates a strong positive correlation ($r > 0.90$) for the majority of morphometric characters (Table 4).

Length-Weight Relationships (LWRs)

The LWRs of both males and females were found to be highly ($p < 0.05$, *t*-test) significant and showed a strong fit ($r^2 > 0.98$) (Table 5). Covariance analysis revealed no significant difference in the regression slopes (*b*) between the sexes (Levene's test for homogeneity of slopes, F-ratio = 0.171; $p > 0.05$). As a result, the data were pooled, and the LWR was derived as $TW = 0.01058\ TL^{3.0764}$ and the same is expressed as $lnTW = -4.54893 + 3.0764\ lnTL$ ($r^2 = 0.9830$). A student *t*-test indicated that the *b* values of males, females, and pooled data were significantly different from the ideal value ($p < 0.05$), signifying hyperallometric growth ($b > 3$) (Table 5).

Weight-Weight Relationships (WWRs)

The linear relationships between the TW and EW of *U. moluccensis* were estimated as follows: $EW = 0.1891 + 0.9394\ TW$ (95 % CI: *a* = 0.0287 –

Table 2 — Morphometric analysis of males and females of *Upeneus moluccensis*

Variable	Male (n = 308)			Female (n = 298)		
	Range (cm)	Mean ± SD (cm)	% CV	Range (cm)	Mean ± SD (cm)	% CV
TL	10.5-19.8	14.47 ± 1.48	10.20	10.6-22.5	15.18 ± 2.07	13.67
SL	8.4-15.8	11.75 ± 1.11	9.46	8.8-18.2	12.41 ± 1.61	12.98
FL	9.3-17.5	12.85 ± 1.25	9.70	9.6-19.8	13.52 ± 1.79	13.21
PDL1	3.0-5.5	4.11 ± 0.41	9.95	3.0-6.6	4.37 ± 0.63	14.44
PDL2	5.5-10.4	7.60 ± 0.75	9.93	5.5-12.2	8.02 ± 1.12	13.99
PPL	2.7-5.1	3.74 ± 0.37	9.90	2.8-6.1	3.97 ± 0.56	14.13
PVL	2.8-5.0	3.88 ± 0.39	9.93	2.9-6.2	4.10 ± 0.58	14.23
PAL	5.7-10.5	7.99 ± 0.79	9.88	5.9-12.8	8.44 ± 1.20	14.21
TKL	6.0-11.4	8.30 ± 0.80	9.66	6.1-12.8	8.74 ± 1.13	12.95
HL	2.6-4.6	3.42 ± 0.33	9.59	2.5-5.7	3.64 ± 0.51	14.11
SNL	0.8-1.6	1.12 ± 0.14	12.10	0.7-2.1	1.20 ± 0.21	17.67
ED	0.7-1.3	0.91 ± 0.11	11.51	0.7-1.8	0.95 ± 0.13	13.61
IOD	0.7-1.3	0.97 ± 0.10	10.08	0.7-1.6	1.03 ± 0.14	13.90
POL	1.1-2.0	1.52 ± 0.15	10.03	1.2-2.5	1.63 ± 0.23	14.16
UJL	0.9-1.7	1.19 ± 0.13	10.95	0.8-2.0	1.28 ± 0.19	15.06
LJL	0.6-1.4	0.92 ± 0.11	11.96	0.6-1.6	0.98 ± 0.15	15.75
DFBL1	1.2-2.8	1.96 ± 0.24	12.50	1.3-3.2	2.06 ± 0.30	14.52
DFBL2	1.0-2.2	1.51 ± 0.17	11.05	1.0-2.6	1.58 ± 0.22	13.80
AFBL	0.9-1.8	1.23 ± 0.13	10.75	0.9-1.8	1.29 ± 0.17	12.96
PFL	1.8-3.7	2.71 ± 0.31	11.57	1.9-4.2	2.86 ± 0.43	15.13
VFL	1.5-2.7	2.03 ± 0.22	10.67	1.5-3.0	2.12 ± 0.28	13.16
CFL	1.8-4.1	2.86 ± 0.36	12.57	2.0-4.5	3.00 ± 0.44	14.65
CD	2.0-4.9	3.08 ± 0.43	14.12	2.0-5.5	3.24 ± 0.52	16.17
CPL	1.8-3.4	2.54 ± 0.29	11.35	1.9-3.7	2.67 ± 0.34	12.73
CPD	0.9-1.7	1.25 ± 0.14	11.03	0.9-2.0	1.31 ± 0.19	14.41
VAL	2.9-5.5	4.07 ± 0.44	10.69	2.9-6.9	4.29 ± 0.65	15.07
BDAO	2.0-4.0	2.89 ± 0.31	10.77	2.0-5.0	3.05 ± 0.42	13.90
BDM	2.3-4.4	3.24 ± 0.35	10.94	2.3-5.5	3.43 ± 0.49	14.41
G1	4.9-9.3	6.38 ± 0.76	11.96	5.0-10.5	6.74 ± 0.98	14.47
G2	5.5-11.5	7.99 ± 1.00	12.46	6.0-13.3	8.51 ± 1.23	14.44
G3	5.3-12.0	8.33 ± 1.10	13.15	6.0-14.0	8.89 ± 1.35	15.15

SD = Standard Deviation; CV = Coefficient of Variation

Table 3 — Index of Morphometric (IM) of different morphometric characters of males and females of *Upeneus moluccensis*

Variable	Male (n = 308)			Female (n = 298)		
	Index range (%)	Mean ± SD	Range difference	Index range (%)	Mean ± SD	Range difference
In Total Length (TL)						
SL	75.19-83.69	81.23 ± 1.37	8.50 $^{\Omega}$	78.03-84.62	81.87 ± 1.31	6.58 $^{\Omega}$
FL	85.80-92.65	88.80 ± 0.97	6.85 $^{\Omega}$	86.12-91.56	89.16 ± 1.00	5.43 $^{\Omega}$
PDL1	21.38-30.83	28.39 ± 0.83	9.45 $^{\Omega}$	26.52-30.77	28.76 ± 0.67	4.25 $^{\Omega}$
PDL2	48.28-54.24	52.51 ± 0.86	5.96 $^{\Omega}$	50.00-55.19	52.84 ± 0.89	5.19 $^{\Omega}$
PPL	24.05-27.78	25.84 ± 0.65	3.73 $^{\Omega}$	24.10-28.67	26.12 ± 0.66	4.57 $^{\Omega}$
PVL	24.24-29.41	26.81 ± 0.83	5.17 $^{\Omega}$	24.57-30.52	27.01 ± 0.83	5.95 $^{\Omega}$
PAL	51.47-59.26	55.26 ± 1.14	7.79 $^{\Omega}$	50.29-58.44	55.62 ± 1.12	8.15 $^{\Omega}$
TKL	53.14-60.65	57.37 ± 1.24	7.50 $^{\Omega}$	52.00-61.39	57.64 ± 1.25	9.39 $^{\Omega}$
HL	21.83-25.49	23.69 ± 0.66	3.66 $^{\Omega}$	21.89-26.57	24.00 ± 0.62	4.68 $^{\Omega}$
DFBL1	10.71-16.23	13.51 ± 0.73	5.52 $^{\Omega}$	11.35-14.97	13.57 ± 0.67	3.62 $^{\Omega}$
DFBL2	7.41-12.86	10.43 ± 0.42	5.45 $^{\Omega}$	8.43-11.56	10.40 ± 0.39	3.12 $^{\Omega}$
AFBL	7.28-9.52	8.50 ± 0.34	2.24 $^{\Omega}$	6.25-10.91	8.49 ± 0.40	4.66 $^{\Omega}$
PFL	14.55-20.92	18.74 ± 0.89	6.37 $^{\Omega}$	15.33-22.42	18.82 ± 1.02	7.09 $^{\Omega}$
VFL	11.72-15.33	14.01 ± 0.48	3.61 $^{\Omega}$	11.97-15.29	13.97 ± 0.52	3.32 $^{\Omega}$
CFL	12.86-22.78	19.73 ± 0.99	9.92 $^{\Omega}$	17.48-23.08	19.76 ± 0.79	5.59 $^{\Omega}$

(*Contd*...)

Table 3 — Index of Morphometric (IM) of different morphometric characters of males and females of *Upeneus moluccensis* (*Contd…*)

Variable	Male (n = 308)			Female (n = 298)		
	Index range (%)	Mean ± SD	Range difference	Index range (%)	Mean ± SD	Range difference
CPL	12.90-21.29	17.56 ± 1.22	8.39[Ω]	14.71-20.89	17.64 ± 1.08	6.18[Ω]
CPD	7.69-9.83	8.61 ± 0.29	2.13[Ω]	7.69-10.40	8.63 ± 0.30	2.71[Ω]
VAL	25.16-32.14	28.16 ± 1.02	6.99[Ω]	24.62-31.80	28.25 ± 0.98	7.18[Ω]
BDAO	14.81-21.89	19.99 ± 0.73	7.08[Ω]	17.93-22.22	20.11 ± 0.62	4.29[Ω]
BDM	19.42-24.38	22.38 ± 0.75	4.95[Ω]	19.31-25.00	22.59 ± 0.75	5.69[Ω]
G1	35.10-50.88	44.07 ± 2.69	15.78[ϰ]	37.09-52.24	44.50 ± 2.74	15.15[ϰ]
G2	45.31-62.43	55.14 ± 2.95	17.12[ϰ]	46.67-61.29	56.06 ± 2.58	14.62[δ]
G3	45.32-65.90	57.48 ± 3.17	20.57[ϰ]	50.98-64.81	58.50 ± 2.58	13.83[δ]
In Head Length (HL)						
SNL	27.59-39.47	32.71 ± 1.89	11.89[δ]	26.32-40.00	32.91 ± 2.10	13.68[δ]
ED	22.58-31.71	26.65 ± 1.40	9.13[Ω]	20.83-31.58	26.13 ± 1.52	10.75[δ]
IOD	25.64-34.21	28.44 ± 1.14	8.57[Ω]	25.00-32.43	28.42 ± 1.10	8.57[Ω]
POL	39.29-50.00	44.34 ± 1.61	10.71[δ]	38.46-50.00	44.67 ± 1.66	11.54[δ]
UJL	27.27-44.74	34.83 ± 1.85	17.46[ϰ]	23.26-40.54	35.02 ± 1.95	17.28[ϰ]
LJL	21.21-36.84	26.90 ± 2.30	15.63[ϰ]	20.59-37.84	26.85 ± 2.38	17.25[ϰ]

[Ω]Genetically controlled character (< 10 %); [δ]Intermediate character (10 – 15 %); [ϰ]Environmentally controlled character (> 15 %)

Table 4 — Linear regression analysis of Length-Length Relationships (LLRs) of *Upeneus moluccensis*

Equation	Male (n = 308)			Female (n = 298)		
	a	***b****	***r***	***a***	***b****	***r***
SL = *a* + *b* TL	0.9865	0.7435	0.9872[£]	0.7052	0.7714	0.9930[£]
FL = *a* + *b* TL	0.6849	0.8402	0.9951[£]	0.4995	0.8581	0.9968[£]
PDL1 = *a* + *b* TL	0.2814	0.2643	0.9551[£]	-0.1895	0.3003	0.9877[£]
PDL2 = *a* + *b* TL	0.2990	0.5042	0.9867[£]	-0.1294	0.5371	0.9926[£]
PPL = *a* + *b* TL	0.2272	0.2425	0.9677[£]	-0.0668	0.2657	0.9834[£]
PVL = *a* + *b* TL	0.2990	0.2472	0.9475[£]	-0.0640	0.2744	0.9758[£]
PAL = *a* + *b* TL	0.4174	0.5235	0.9786[£]	-0.2389	0.5721	0.9894[£]
TKL = *a* + *b* TL	0.6208	0.5304	0.9765[£]	0.5781	0.5377	0.9857[£]
HL = *a* + *b* TL	0.3293	0.2139	0.9607[£]	-0.0467	0.2431	0.9815[£]
DFBL1 = *a* + *b* TL	-0.2240	0.1507	0.9090[£]	0.0084	0.1351	0.9377[£]
DFBL2 = *a* + *b* TL	-0.0093	0.1049	0.9286[£]	0.0520	0.1005	0.9578[£]
AFBL = *a* + *b* TL	0.0301	0.0829	0.9253[£]	0.1592	0.0742	0.9244[£]
PFL = *a* + *b* TL	-0.0937	0.1939	0.9122[£]	-0.0966	0.1947	0.9340[£]
VFL = *a* + *b* TL	0.0167	0.1389	0.9477[£]	0.1587	0.1291	0.9609[£]
CFL = *a* + *b* TL	-0.3867	0.2243	0.9210[£]	-0.0846	0.2033	0.9594[£]
CD = *a* + *b* TL	-0.1650	0.2241	0.7611[§]	0.1056	0.2067	0.8176[§]
CPL = *a* + *b* TL	0.3271	0.1528	0.7829[§]	0.4785	0.1444	0.8816[§]
CPD = *a* + *b* TL	-0.0369	0.0887	0.9518[£]	-0.0299	0.0883	0.9705[£]
VAL = *a* + *b* TL	0.0723	0.2765	0.9370[£]	-0.3103	0.3033	0.9726[£]
BDAO = *a* + *b* TL	0.0281	0.1980	0.9381[£]	0.0338	0.1989	0.9723[£]
BDM = *a* + *b* TL	-0.0695	0.2287	0.9518[£]	-0.0779	0.2312	0.9700[£]
G1 = *a* + *b* TL	-0.1023	0.4477	0.8661[§]	0.2938	0.4251	0.9034[£]
G2 = *a* + *b* TL	-0.8924	0.6137	0.9098[£]	0.0115	0.5598	0.9451[£]
G3 = *a* + *b* TL	-1.5680	0.6842	0.9212[£]	-0.5230	0.6200	0.9552[£]
SNL = *a* + *b* HL	-0.1197	0.3623	0.8776[§]	-0.2157	0.3894	0.9415[£]
ED = *a* + *b* HL	-0.0557	0.2829	0.8843[§]	0.1261	0.2260	0.8989[§]
IOD = *a* + *b* HL	0.0379	0.2732	0.9149[£]	0.0567	0.2684	0.9593[£]

(*Contd…*)

Table 4 — Linear regression analysis of Length-Length Relationships (LLRs) of *Upeneus moluccensis* (*Contd.*)

Equation	**Male (n = 308)**			**Female (n = 298)**		
	a	***b****	***r***	***a***	***b****	***r***
UJL = $a + b$ HL	0.0131	0.3445	0.8668[§]	0.0275	0.3426	0.9161[£]
LJL = $a + b$ HL	0.1309	0.2304	0.6882[¥]	0.0917	0.2430	0.8114[§]

*$p < 0.05$; a = intercept; b = slope; r = correlation coefficient; [£]High correlation (> 0.90); [§]Good correlation (0.75 – 0.90); [¥]Moderate correlation (0.50 – 0.75)

Table 5 — Length-Weight Relationships (LWRs) of *Upeneus moluccensis* from the northeastern Arabian Sea

Parameter	**Male**	**Female**	**Pooled**
Sample size (N)	308	298	606
TL range (cm)	10.5 – 19.8	10.6 – 22.5	10.5 – 22.5
Total Weight (TW) range (g)	11.67 – 103.47	15.02 – 143.53	11.67 – 143.53
Regression parameters			
Intercept (a)	0.01045	0.01157	0.01058
95 % CI of a	0.00898 – 0.01215	0.01028 – 0.01304	0.00958 – 0.01168
Slope (b)	3.0742	3.0491	3.0764
95 % CI of b	3.0175 – 3.1309	3.0050 – 3.0932	3.0397 – 3.1131
Coefficient of determination (r^2)	0.9812	0.9869	0.9830
Standard error of b (S_b)	0.0288	0.0224	0.0187
Student's t-test			
$|t$-value$|$	2.580	2.193	4.086
p-value	0.01*	0.02*	0.00*
Growth type	Hyperallometric	Hyperallometric	Hyperallometric

*$p < 0.05$; CI = Confidence Interval

Table 6 — Monthly changes in the relative condition factor (K_n) and Fulton condition factor (K_F) of *Upeneus moluccensis*

Month	K_n		K_F	
	Male	**Female**	**Male**	**Female**
Sept	1.0018±0.0609	1.0010±0.0479	1.2199±0.0839	1.2768±0.0618
Oct	1.0008±0.0406	1.0005±0.0321	1.3092±0.0546	1.3216±0.0456
Nov	1.0009±0.0424	1.0008±0.0396	1.3715±0.0623	1.3863±0.0586
Dec	1.0015±0.0559	1.0025±0.0722	1.2044±0.0722	1.2352±0.0912
Jan	1.0015±0.0567	1.0012±0.0500	1.2906±0.0765	1.3377±0.0717
Feb	1.0015±0.0547	1.0012±0.0498	1.2753±0.0699	1.2861±0.0654
Mar	1.0024±0.0692	1.0028±0.0754	1.2138±0.0870	1.3093±0.1008
Apr	1.0014±0.0557	1.0012±0.0501	1.2707±0.0723	1.3226±0.0677
May	1.0022±0.0690	1.0008±0.0413	1.2723±0.0899	1.2789±0.0527
Aug	1.0021±0.0663	1.0016±0.0586	1.1968±0.0997	1.2282±0.0727

0.3496; b = 0.9355 – 0.9432) for males; $EW = 1.2673 + 0.9038\ TW$ (95 % CI: a = 1.0340 – 1.5005; b = 0.8994 – 0.9082) for females; and $EW = 1.1011 + 0.9114\ TW$ (95 % CI: a = 0.9451 – 1.2571; b = 0.9081 – 0.9147) for pooled data. The regression analysis showed a high correlation ($r > 0.999$) and was found to be statistically significant ($p < 0.05$, t-test). The TW of pooled samples of *U. moluccensis* was found to be 6.1 % greater than the EW.

Condition factors

The monthly K_n of *U. moluccensis* was highest in March (1.0024±0.0692 for males and 1.0028±0.0654 for females) and lowest in October (1.0008±0.0406 for males and 1.0005±0.0321 for females) (Table 6). The highest and lowest K_F values for both sexes were recorded in November and August, respectively (Table 6). Monthly variations in body condition indicated that the maximum percentage of lean fishes was recorded in October and August for males, and from September to October and February to April for females (Fig. 2). The Wilcoxon signed-rank test revealed that the average relative weight (W_R) of males (100.28±7.4) and females (100.20±6.33) did not significantly differ from 100 (p = 0.36 for males; p = 0.58 for females).

Form factor and life-history traits

The $_{average}$ $a_{3.0}$ value of *U. moluccensis* was calculated as 0.0132 for males, 0.0135 for females, and 0.0134 for the pooled data. Based on the maximum Total Length (TL_{max}) (males = 19.8 cm; females = 22.5 cm), various life history traits were calculated and are presented in Table 7.

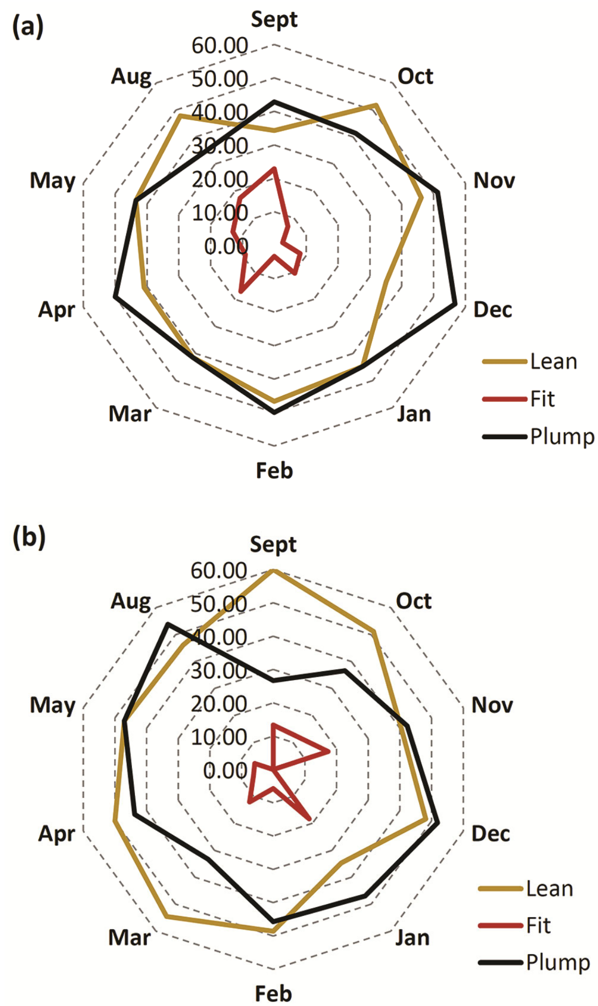

Fig. 2 — Monthly changes in the corporeal status based on allometric condition factor (K_A) of (a) Males; and (b) Females of *Upeneus moluccensis*

Size-based estimates

The catch composition of *U. moluccensis* was analysed using sustainability indicators to determine the proportion of mature (P_{mat}), optimally sized (P_{opt}) and mega-spawner (P_{mega}) fishes. The results of size-based estimates revealed that the proportion of mature, optimally sized, and mega-spawners ranged from 59 to 92 %, 48 to 63 %, and 17 to 50 %, respectively (Fig. 3). Maximising the production of Goldband goatfish requires targeting size classes between 11.7 – 14.3 cm for males and 13.3 – 16.3 cm for females and pooled data. According to the decision tree for the established size-based estimates ($1 < P_{obj} < 2$ and $L_m = 0.9\ L_{opt}$), the stock of *U. moluccensis* is likely to be overfished, with Spawning Biomass (SB) below the TRP, showing overfishing probabilities of 44 % for males and 100 % for females and pooled data. Similarly, the probabilities of overfishing relative to the Limit Reference Point (LRP) were 22 % for males and 100 % for females and pooled data.

Discussion

The present study provides comprehensive information on the biometric and life-history traits of *U. moluccensis* from the northwest coast of India. Chi-square test showed no significant difference ($p > 0.05$) from the ideal ratio (1:1), suggesting a balanced sex ratio, which is typically considered ideal for successful reproduction in fishes[37]. A similar non-significant sex ratio was reported for *U. moluccensis* from the Maharashtra coast[38] and the Eastern Mediterranean Sea[10]. In contrast, a predominance of females was reported for *U. moluccensis* from the Indonesian coast[39] and the Turkish coast[6]. This

Table 7 — Form factor ($a_{3.0}$) and life-history traits of *Upeneus moluccensis*

Parameter	Male	Female	Pooled
Maximum Total Length (L_{max}) (cm)	19.8	22.5	22.5
Form factor ($a_{3.0}$)	0.0132	0.0135	0.0134
Asymptotic length ($L\infty$) (cm)	20.9	23.7	23.7
Asymptotic weight ($W\infty$) (g)	119.46	179.84	179.29
Size at first sexual maturity (L_m) (cm)	12.8	14.3	14.3
Age at first sexual maturity (t_m) (years)	0.95	0.93	0.93
Longevity (t_{max}) (years)	3.4	3.3	3.3
Growth performance index ($Ø'$)	2.59	2.71	2.71
Natural mortality (M_W) ($year^{-1}$)	1.61	1.64	1.64
Optimum catchable length (L_{opt}) (cm)	13.0	14.8	14.8

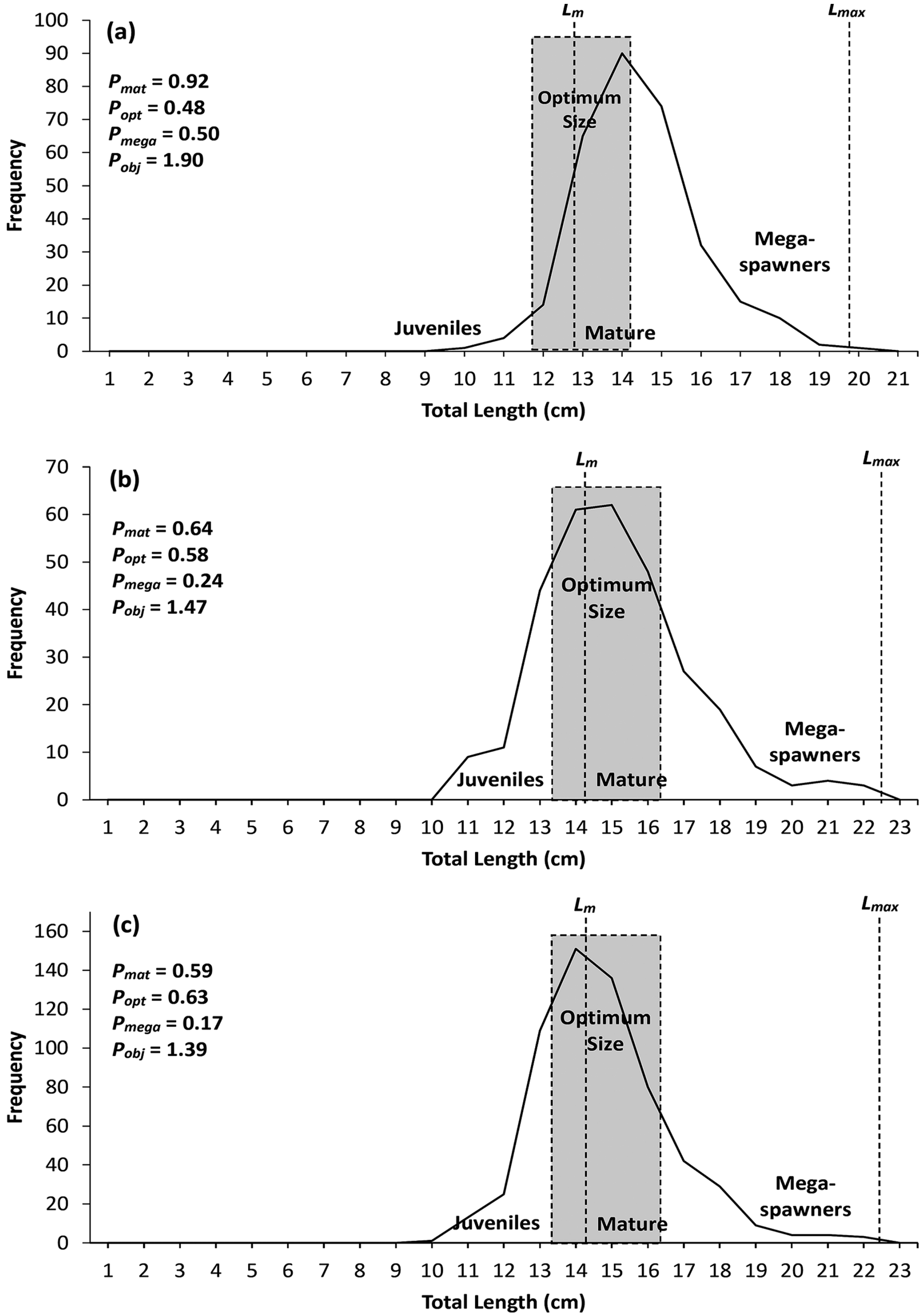

Fig. 3 — Relative position of size indicators of (a) Males, (b) Females, and (c) Pooled data of *Upeneus moluccensis*

deviation in other geographic regions could be attributed to differential vulnerability to fishing gear, segregation for spawning and feeding purposes, or differences in growth rates and natural mortality between males and females[40]. However, the significant imbalance in sex ratio ($p < 0.05$, χ^2 test) observed in different size groups might be explained by variations in growth patterns and life-history attributes, as male *U. moluccensis* grow faster in the first year but their growth slows down thereafter, while females grow somewhat faster after reaching two years of age and have a longer lifespan[10]. Previous investigations on the size range of *U. moluccensis* differ from the current study (10.5 – 19.8 cm for males and 10.6 – 22.5 cm for females), as moderately smaller size samples were recorded from Veraval coast (11.6 – 16.1 cm)[9], Kakinada coast (12.2 – 17.5 cm)[17], and Mediterranean Sea (10.4 – 18.8 cm)[16]. The size range documented by Ismen[10] from the Bay of Iskenderun (7.0 – 20.5 cm) and by Bilge *et al.*[12] from the Aegean Sea (7.9 – 22.5 cm) aligns with the total length range of the current analysis (10.5 – 22.5 cm).

The average morphometric values and CV of females were higher than those of males for all variables. The higher CV observed in females suggests increased phenotypic variability, likely influenced by reproduction or maturity stage[41]. The CV was found to be < 16 % for all traits in both sexes, except for CFD and SnL in females, suggesting minimal intra-population variation, high inheritability, and a limited effect of environmental conditions on the morphometry of the species[42]. Species with broad geographic distributions tend to exhibit a greater number of environmentally controlled characters, whereas fish with restricted distributions tend to exhibit a greater number of genetically controlled characters[43]. In the present study, *U. moluccensis* appears to have a restricted distribution, as a large number of characters were controlled by genetic components, indicating the populations are geographically or reproductively isolated. The fin formula determined in this study aligns with previous reports[3,44].

The linear relationships of different morphometric features showed a high growth rate ($b > 0.743$) and a strong correlation ($r > 0.987$) for SL and FL for both sexes. Similarly, a high growth rate with a high correlation value ($r = 0.97 – 0.99$) in SL and FL was observed in *Mullus barbatus*[45] and *Parupeneus barberinus*[46], paralleling the present study. Furthermore, the linear relationships revealed higher growth rates for only eight characters (DFBL1, CFL, CFD, CPL, G1, G2, G3, and ED) in males, whereas all other characters exhibited higher growth rates in females.

The b value of LWRs of *U. moluccensis* from the northwest coast of India indicated hyperallometric/ positive allometric growth ($b > 3$), suggesting that the fish gain more weight relative to their length. This pattern is consistent with findings for pooled individuals from the southeast coast of India ($b = 3.60$)[17], north Cyprus coast ($b = 3.33$)[16], and Aegean Sea waters ($b = 3.14$)[12]. In contrast, isometric growth ($b = 3$) was observed in Turkish waters[10] and Egyptian Mediterranean waters[14], while hypoallo metric growth ($b = 2.74$) was reported from the Veraval coast[9]. This variation in growth patterns could be attributed to factors such as reproductive stage, feeding intensity, stock structure, and geographical conditions[47]. These LWRs results suggest that the population of *U. moluccensis* allocates more energy towards somatic growth, indicating favourable growth conditions. The WWRs equations derived in this study are vital for estimating eviscerated weight from whole weight. The recorded evisceration yield in the current study (93 %) would allow precise budgeting of raw materials and processing capacities in seafood and surimi industries.

The condition factor provides essential information on the biological and physiological status of fish, which is crucial for the conservation and management of natural populations[48]. The minimum relative condition factor (K_n) value recorded during post-monsoon (September to November) for both males and females could be correlated with the poor feeding on crustaceans[6]. The average Fulton condition factor (K_F) exceeded 1.20 across all months and size groups, indicating high prey availability and favourable environmental conditions for the growth and survival of the species. The mean values of corporeal status highlighted plump, fit individuals were more common among males, while leaner individuals were more frequently observed among females. The presence of more lean individuals during September and October in this study may be linked to the peak breeding season[11]. The mean W_R was not significantly different from 100 (Wilcoxon signed ranked test, $p > 0.05$), indicating a stable population condition. The K_n value of other species, such as *U. sulphureus* ranged from 0.70 to 1.79[ref. 49], while those of *U. sundaicus* and *U. tragula* ranged from 0.80 to 1.68[ref. 50].

The relationships of form factor ($a_{3.0}$) value and body shape were studied by Froese[23], who reported that the $a_{3.0}$ value increases from eel-like (0.0013) to elongated (0.0083), fusiform (0.0137), and short or deep-bodied (0.0187) shapes. The $a_{3.0}$ value in this study (0.0134, pooled) indicated a fusiform type of body shape. The first estimate of the $a_{3.0}$ value in the present study serves as a valuable addition to the data archive. Life-history traits are among the most widely used approaches in the management and conservation of fishery resources, as they provide detailed, precise information while being relatively inexpensive and easy to collect[51]. The $L\infty$ of *U. moluccensis* recorded in the present study (pooled = 23.7 cm) is comparable to the findings of Mehanna[14] from Egyptian Mediterranean waters (22.9 cm). However, higher $L\infty$ values were reported in earlier studies from the Gulf of Antalya (25.6 cm)[11], the Red Sea (33.1 cm)[15], Iskenderun Bay (25.2 cm)[10] and the Aegean Sea (26.2 cm)[6]. These variations in $L\infty$ could be linked to the effects of global warming, as elevated sea surface temperature can lead to lower dissolved oxygen levels in the water, which are crucial for fish growth and development[52].

In the present study, males (12.8 cm) of *U. moluccensis* mature earlier than females (14.3 cm), which correlates with the previous study by Abdullah *et al.*[53] from the Indonesian coast (15.0 cm for males and 16.6 cm for females). The greater energy expenditure by females for ovary and egg development may explain their delayed maturation[54]. The correlation of size at first sexual maturity with size-frequency proclaimed that only 8.44 % males examined were juveniles, while 35.57 % females were found below the L_m. Furthermore, t_{max} of *U. moluccensis* recorded in this study was 3.3 years (pooled data). Vivekanandan *et al.*[55] reported that the longevity of goatfishes is approximately three years, whereas Reed & Taylor[56] suggested that the maximum lifespan for goatfish species (*P. barberinus* and *Mulloidichthys flavolineatus*) can be up to five years.

The growth performance index ($Ø'$) of *U. moluccensis* calculated in this study (2.71) was similar to other goatfish species, such as *U. sulphureus* (2.650)[57] and *Mulloidichthys vanicolensis* (2.765)[15], confirming the observation that $Ø'$ tend to be consistent across related genera, species or families[58]. In the current investigation, natural mortality (M_W) was found to be higher in females (1.64 $year^{-1}$) compared to males (1.61 $year^{-1}$). Similar values were reported in *U. sulphureus* (1.49 $year^{-1}$)[57] and *U. tragula* (1.38 $year^{-1}$)[59].

To prevent overfishing and promote responsible use of aquatic resources, Froese[33] recommends the use of simple stock indicators derived from length-frequency data to assess whether a stock is being harvested sustainably. This approach helps categorise the individual fish as juvenile, mature, optimal size, or mega-spawner, which can be easily understood by all fisheries stakeholders, encouraging their active participation in effective fisheries management. The results of this study revealed that only males have P_{mat} values (> 90 %), nearly reaching the target of 100 %. In contrast, for females and pooled data, only 60 % of the catch corresponded to mature individuals, indicating that more than one-third of the population is excluded from reproduction. The application of a decision tree suggested that the spawning stock of Goldband goatfish is below the target and limit reference points, highlighting elevated risk of overfishing in the absence of appropriate management measures[34,35]. Also, probabilities of overfishing are higher in females than in males, which could be attributed to sex-related vulnerability, as females often attain larger sizes and might exhibit different spatio-temporal aggregations[60]. Therefore, it is recommended that fish of optimal size (13.3 – 16.3 cm) be harvested to maintain the rational exploitation of the species in the studied locality each year.

Conclusion

The present investigation provides essential information on the biometric parameters and life-history traits of Goldband goatfish along the northwest coast of India, serving as a valuable data archive for future studies on feeding and reproductive biology, population genetic analysis, and nutritional evaluation. The low CV (< 16 %) observed in most morphometric characteristics indicate a homogeneous population with low intra-population variation. Additionally, it is recommended that fishing be restricted during September – October, coinciding with the peak spawning season, as a measure to protect the spawning stock and ensure sustainable exploitation. Size-based estimates suggested that 13.3 – 16.3 cm is the optimal legal size for harvesting the species, providing baseline information to support effective fisheries management measures.

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Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

NKS: Sample collection, investigation, data analysis, and writing – original draft. DTV: Conceptualisation, methodology, data analysis, and writing – review and editing. RM: Conceptualization, Methodology, and writing – review and editing. KMR: Writing – review and editing. BS: Formal analysis and writing – review and editing.

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