

# Ecological characteristics, biodiversity, essential amino acid, and fatty acid composition of mahseer (*Tor* sp.) in upstream of Mount Foot of Slamet waters, Central Java, Indonesia

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**Abstract.** Freshwater biodiversity is declining globally, and several mahseer species (*Tor* sp.) are currently threatened due to habitat degradation and overexploitation. In Indonesia, mahseer inhabit fast flowing upstream rivers and play important ecological and nutritional roles. This study presents an integrated assessment of ecological characteristics, biodiversity, and nutritional quality of mahseer (*Tor* sp.) from four upstream rivers at the foot of Mount Slamet, Central Java, namely the Pelus, Tutung Gunung, Comal, and Welo Rivers. Water quality parameters indicated favorable habitat conditions for mahseer, with high dissolved oxygen, moderate temperatures, near neutral pH, and substrates dominated by rocks, gravel, and sand. Two species, *Tor tambra* and *Tor tambroides*, were recorded, with species composition and diversity varying among rivers. Amino acid analysis revealed complete profiles at all sites, with essential amino acids accounting for 33.61-39.04% of total amino acids, lysine being the most dominant. Non essential amino acids, particularly glutamic and aspartic acids, predominated and contributed to metabolic and sensory properties. Fatty acid profiles were characterized by a dominance of unsaturated fatty acids (63.63-71.80%), including nutritionally important omega 3 fatty acids (EPA and DHA). Spatial variation in amino acid and fatty acid composition suggests the influence of habitat conditions and food availability. Overall, this study demonstrates that upstream habitats at the foot of Mount Slamet support ecologically and nutritionally valuable mahseer populations, highlighting the importance of habitat conservation for sustaining freshwater biodiversity and fish nutritional quality.

**Keywords:** biodiversity index, freshwater fish, habitat quality, nutrient composition, rheophilic species, tropical river.

**Introduction.** Freshwater ecosystems are among the most biodiverse yet most threatened ecosystems globally, experiencing rapid species declines due to habitat degradation, overexploitation, pollution, and hydrological alteration. Freshwater fishes, particularly migratory and rheophilic species, are disproportionately affected by these pressures, making them sensitive indicators of riverine ecosystem health (Reid et al 2019; Dudgeon 2020). Among the diverse aquatic fauna inhabiting these ecosystems, mahseers (*Tor* sp.) represents a group of freshwater fish with high ecological, economic, and conservation significance. These species are widely distributed across South and Southeast Asia, including Indonesia, where they are commonly found in the upper reaches of rivers on the islands of Sumatra, Java, and Kalimantan, particularly in mountainous areas covered by tropical forests (Atifah et al 2021). Mahseer are known for their sensitivity to environmental fluctuations, making them valuable bioindicators for assessing the health and integrity of riverine ecosystems (Pinder et al 2019). Understanding the ecological of *Tor* sp. is therefore crucial for informing conservation strategies and sustainable management of freshwater resources.

Mahseer species are large bodied, migratory cyprinids that typically inhabit clear, fast flowing upstream rivers with high dissolved oxygen and coarse substrates composed of rocks and gravel (Haryono & Subagja 2008; Desrita et al 2019; Dhawan et al 2023;

Tiwari et al 2025). Numerous studies across Asia have documented that *Tor* spp. require pristine headwater habitats and are highly sensitive to changes in water quality, flow regime, and river connectivity (Jaafar et al 2021; Akhtar & Ciji 2023). Recent surveys have confirmed that habitat fragmentation, overfishing, dam construction, and land use change are primary drivers of mahseer population decline, leading to local extirpations even within historically suitable rivers (Roesma et al 2016; Desrita et al 2019; Dudgeon 2020; Jaafar et al 2021; Naik et al 2024).

In Indonesia, mahseer species such as *Tor tambra* and *Tor tambroides* are native to mountainous river systems on the islands of Java, Sumatra, and Kalimantan. Although these species are increasingly recognized for their conservation importance, empirical data on their ecology, biodiversity patterns, and nutritional quality remain uneven and geographically limited. Previous studies in Sumatra and Aceh have largely focused on population structure, habitat characteristics, or reproductive biology (Desrita et al 2019; Atifah et al 2021; Akmal et al 2022), while comparable information from Java, particularly Central Java, remains scarce.

Recent ecological studies emphasize that biodiversity patterns of mahseer are strongly influenced by local habitat conditions, riparian integrity, and river connectivity. Rivers with higher habitat heterogeneity and lower anthropogenic disturbance tend to support greater species coexistence, whereas simplified or disturbed headwaters often exhibit single species dominance and low diversity indices (Pinder et al 2019; Dudgeon 2020; Magurran 2021). Such spatial heterogeneity has been reported in Indonesian rivers, where mahseer diversity varies substantially even among adjacent catchments (Haryono & Subagja 2008; Arif et al 2025).

Beyond ecological and conservation relevance, mahseer are also nutritionally valuable freshwater fishes. Fish nutritional quality is primarily determined by muscle protein composition, particularly essential amino acids (EAAs), and lipid fraction dominated by unsaturated fatty acids (UFAs). EAAs such as lysine, leucine, and threonine are indispensable for human growth and metabolism and cannot be synthesized endogenously (Church et al 2020; Paoletti et al 2024). Studies on freshwater fishes consistently show that EAA profiles vary among populations in response to diet composition, habitat productivity, and environmental stressors (Azrita et al 2024; Das et al 2024; Khan et al 2024).

Similarly, fatty acid composition in freshwater fishes reflects both dietary sources and habitat specific energy pathways. Unsaturated fatty acids, particularly omega 3 long chain polyunsaturated fatty acids (PUFAs) such as EPA and DHA, are influenced by aquatic primary productivity and benthic-pelagic energy transfer in river ecosystems (Všetičková et al 2019; Ebm et al 2021; Yan et al 2024). Fatty acid profiles are increasingly used as ecological tracers to infer habitat use, food availability, and environmental quality in riverine fishes (Li et al 2023; Wu et al 2024; Prananda et al 2025).

Recent nutritional and ecological studies emphasize that amino acid and fatty acid compositions in fish muscle are tightly linked to habitat conditions, feeding ecology, and energy allocation strategies (Li et al 2020; Chasanah et al 2021; Shapawi et al 2025). Consequently, integrating ecological characteristics, biodiversity metrics, and nutritional composition provides a more comprehensive understanding of how freshwater fishes respond to environmental variability and anthropogenic pressures.

The upstream rivers at the foot of Mount Slamet, Central Java, represent important yet understudied headwater ecosystems that support native mahseer populations. These rivers exhibit varying degrees of habitat integrity and human influence, offering a unique opportunity to examine how ecological conditions and biodiversity patterns relate to nutritional quality within a single geographic region. To date, no study has simultaneously evaluated ecological habitat characteristics, mahseer biodiversity, and muscle amino acid and fatty acid composition in these river systems.

Therefore, the present study aims to provide an integrated assessment of (i) ecological characteristics of upstream rivers at the foot of Mount Slamet, (ii) biodiversity and distribution patterns of mahseer (*Tor* sp.), and (iii) essential amino acid and fatty acid composition of mahseer populations across different river systems. This integrated

approach is expected to contribute baseline data for mahseer conservation, support sustainable management of headwater ecosystems, and highlight the dual ecological and nutritional value of mahseer as an indigenous freshwater fish in Indonesia.

## Material and Method

**Description of the study sites.** The study was conducted from June to October 2024 in four upstream rivers located at the foothills of Mount Slamet, Central Java, Indonesia. These selected locations were the Pelus River in Banyumas Regency, the Tutung Gunung River in Purbalingga Regency, the Comal River in Pemalang Regency, and the Welo River in Pekalongan Regency (PKL). The geographical coordinates of the upstream sampling points are as follows: Pelus River at  $7^{\circ}18'24.907''$  S,  $109^{\circ}14'32.282''$  E; Tutung Gunung River at  $7^{\circ}13'17.903''$  S,  $109^{\circ}20'46.947''$  E; Comal River at  $7^{\circ}12'18.832''$  S,  $109^{\circ}14'42.431''$  E; and Welo River at  $7^{\circ}9'23.795''$  S,  $109^{\circ}44'48.072''$  E (Figure 1). These sites were selected based on their ecological significance and represent diverse upstream environments within the region.

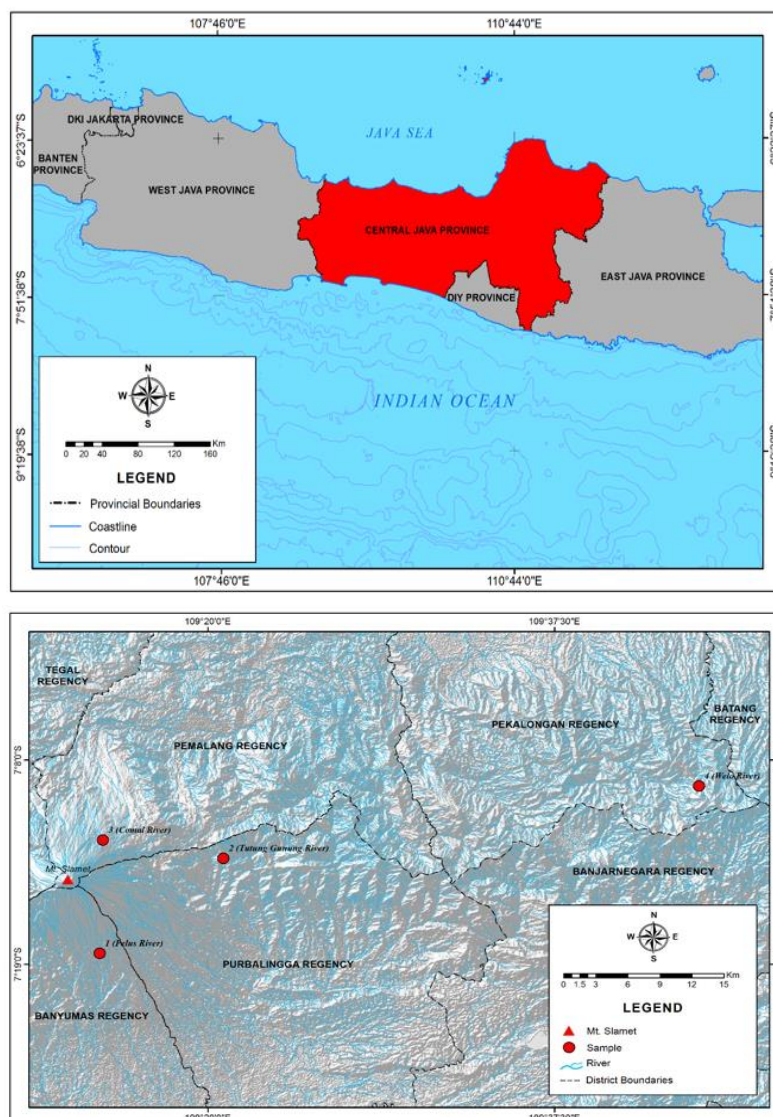


Figure 1. Map showing the four upstream river research sites located at the foothills of Mount Slamet, Central Java, Indonesia.

**The ecological characteristics.** The ecological characteristics of *Tor* sp. were determined by measuring physical-chemical parameters (temperature, dissolved oxygen (DO), pH, total dissolved solids (TDS), ammonia, nitrite), current velocity, water depth,

and bottom water substrate in situ. Water quality parameters were measured in situ every two weeks during the study period. Water temperature and DO were measured using a DO Meter Lutron-5510, while TDS and pH were measured using a TDS Tester Hanna DiST1. Ammonia and nitrite concentrations were analyzed using a spectrophotometer following standard colorimetric methods. Current velocity was measured using a flow meter, and water depth was measured using a calibrated measuring rod. In addition, bottom substrate samples were collected from the riverbed and their composition was visually examined and recorded. These environmental assessments were complemented by direct observations of *Tor* sp. individuals captured from the upstream sections of the four rivers, providing insights into their habitat preferences and ecological responses to local environmental conditions.

**Fish sampling and tissue preservation.** Fish samples were collected from four main upstream river locations situated at the foot of Mount Slamet, Central Java Province, Indonesia. These sites were selected based on their ecological relevance and the presence of *Tor* sp. populations. Sampling was conducted using standardized protocols to ensure consistency across locations, with particular attention to minimizing environmental disturbance. Fish specimens were captured using fishing rods and hand nets every two weeks. The fish captures were carried out with the assistance of local community members experienced in catching fish.

Each individual was measured for total length (cm) and body weight (g). A caudal fin and a small portion of dorsal muscle were aseptically excised using sterilized instruments. Tissue samples were preserved in 70% ethanol in labelled microtubes and stored at room temperature prior to molecular analysis at the Aquaculture Laboratory, Faculty of Agriculture and Fisheries, Universitas Muhammadiyah Purwokerto.

**Biodiversity of mahseers.** The biodiversity of mahseer populations in each river was evaluated using ecological diversity indices. The Shannon-Wiener diversity index and Simpson dominance index (Odum 1993) were calculated based on species abundance data. The Shannon–Wiener diversity index was calculated as:

$$H' = - \sum (p_i \ln p_i)$$

where:  $p_i$  = proportion of individuals belonging to the  $i$ -th species;

$$p_i = n_i/N;$$

$n_i$  = number of individuals of species  $i$ ;

$N$  = total number of individuals.

The Simpson index was calculated as:

$$D = 1 - \sum (p_i^2)$$

where:  $p_i$  = proportion of individuals belonging to the  $i$ -th species.

**Essential amino acids and fatty acids composition of mahseers.** Amino acid composition was determined following the AOAC (2003) protocol. Samples were initially dried and defatted using a chloroform-methanol mixture. Protein hydrolysis was subsequently carried out with 6N hydrochloric acid (HCl) at 110 °C for 24 h. After hydrolysis, the samples were neutralized with 6N NaOH, followed by derivatization prior to chromatographic analysis. The derivatized samples were analyzed using High-Performance Liquid Chromatography (HPLC) equipped with a LiChrospher 100 RP-18 column (5  $\mu$ m). The mobile phase consisted of solvent A (CH<sub>3</sub>OH: 50 mM sodium acetate: tetrahydrofuran, 2:96:2, pH 6.8) and solvent B (65% CH<sub>3</sub>OH). Gradient elution was applied, starting with 100% solvent A and progressively transitioning to 35% solvent A and 65% solvent B over 30 min. The injection volume was 10  $\mu$ L, and the mobile phase flow rate was maintained at 1.5 mL min<sup>-1</sup>. Amino acids were detected using a Thermo Dionex UltiMate 3000 RS fluorescence detector with excitation and emission wavelengths set at 300 nm and 500 nm, respectively. System calibration was performed using standard amino acid solutions to assess chromatographic separation and detector

response. Calibration curves were established across a range of standard concentrations, and replicate analyses were conducted to ensure analytical accuracy, precision, and reproducibility (Nurfaidah et al 2024).

Crude lipid extraction was performed using chloroform:methanol (1:1, v/v). The lipid extracts were transmethylated into fatty acid methyl esters (FAME) using sodium hydroxide–methanol and hydrogen chloride–methanol. Fatty acid profiles were analyzed using a gas chromatograph (Shimadzu GC-2010, Shimadzu Corporation, Kyoto, Japan). Separation was carried out on a capillary column (BPX70; 60 m × 0.25 mm ID, SGE Australia Pty. Ltd., Ringwood, Vic., Australia). Identification of chromatographic peaks was achieved by comparing retention times with those of FAME standards (Supelco™ 37 Component FAME Mix, Supelco Inc., Bellefonte, USA) (Shapawi et al 2025).

**Statistical analysis.** Descriptive statistics were used to summarize ecological characteristics, biodiversity, essential amino acid, and fatty acid composition of mahseer (*Tor* sp.).

**Results.** Mount Slamet, an active volcano in Central Java, is a major source of freshwater springs that feed several rivers flowing through its southern, eastern, and northern regions. The Pelus River (Banyumas Regency) flows from the southern slope, the Tutung Gunung River (Purbalingga Regency) from the eastern slope, and both the Comal River (Pemalang Regency) and Welo River (Pekalongan Regency) from the northern slope. This study generated data on the ecological conditions of the mahseer (*Tor* sp.) populations across four upstream river locations: the Pelus, Tutung Gunung, Comal, and Welo Rivers.

**The ecological characteristics.** The ecological characteristics of the four river systems inhabited by mahseer (*Tor* sp.) in Central Java are presented in Table 1. Water quality parameters showed relatively similar conditions among sampling locations, although several variables exhibited noticeable variation.

Table 1  
Ecological conditions at Pelus River, Tutung Gunung River, Comal River, and Welo River, Central Java, Indonesia

Ecological conditions	Locations			
	Pelus River	Tutung Gunung River	Comal River	Welo River
Dissolved oxygen (mg L <sup>-1</sup> )	7.6±0.6	8.3±0.4	7.4±0.3	7.7±0.1
pH	7.8±0.3	7.9±0.2	7.7±0.4	7.6±0.1
Ammonia (mg L <sup>-1</sup> )	0.08±0.011	0.03±0.004	0.06±0.015	0.04±0.002
Nitrite (mg L <sup>-1</sup> )	0.012±0.002	0.008±0.001	0.034±0.006	0.030±0.01
Water temperature (°C)	22.5±2	23.5±1	25.0±2	24.5±0.3
Total dissolved solid (mg L <sup>-1</sup> )	84±11	64±15	66±17	53±13
Current velocity (m s <sup>-1</sup> )	3.4±0.4	3.5±0.2	2.6±0.2	4.6±0.3
River depth (cm)	42-83	30-80	30-91	30-110
River bottom substrate	Sand, gravel, rock	Sand, gravel, rock	Sand, gravel, rock	Sand, gravel, rock

DO concentrations ranged from 7.4±0.3 to 8.3±0.4 mg L<sup>-1</sup>. The highest DO level was recorded in the Tutung Gunung River (8.3±0.4 mg L<sup>-1</sup>), whereas the lowest was observed in the Comal River (7.4±0.3 mg L<sup>-1</sup>). Despite these differences, all rivers exhibited relatively high oxygen availability, suggesting well-aerated aquatic environments.

Water pH values were relatively stable among locations, ranging from 7.6±0.1 to 7.9±0.2. The Tutung Gunung River showed the highest pH (7.9±0.2), while the Welo River exhibited the lowest value (7.6±0.1). These results indicate that all rivers maintained near-neutral to slightly alkaline conditions.

Nitrogen-related water quality parameters also differed among rivers. Ammonia concentrations varied from 0.03±0.004 to 0.08±0.011 mg L<sup>-1</sup>. The lowest ammonia level was detected in the Tutung Gunung River, whereas the highest concentration occurred in the Pelus River. Similarly, nitrite concentrations ranged from 0.008±0.001 mg L<sup>-1</sup> in the

Tutung Gunung River to  $0.034 \pm 0.006 \text{ mg L}^{-1}$  in the Comal River. Overall, nitrogenous waste concentrations remained low across all study sites.

Water temperature showed moderate variation among rivers, ranging from  $22.5 \pm 2.0^\circ\text{C}$  in the Pelus River to  $25.0 \pm 2.0^\circ\text{C}$  in the Comal River. The Tutung Gunung and Welo rivers exhibited intermediate temperatures of  $23.5 \pm 1.0^\circ\text{C}$  and  $24.5 \pm 0.3^\circ\text{C}$ , respectively.

TDS varied considerably among locations, with values ranging from  $53 \pm 13$  to  $84 \pm 11 \text{ mg L}^{-1}$ . The highest TDS concentration was recorded in the Pelus River, while the Welo River showed the lowest value. The Tutung Gunung and Comal rivers exhibited intermediate TDS levels of  $64 \pm 15$  and  $66 \pm 17 \text{ mg L}^{-1}$ , respectively.

Current velocity ranged from 2.6 to  $4.6 \text{ m s}^{-1}$ , with the highest value recorded in the Welo River, indicating moderate to strong flow conditions. Water depths ranged from 30 and 110 cm across all study sites, with shallower sections dominated by juveniles and deeper rivers accommodating larger individuals.

The bottom substrate, consisting of sand, gravel, and rocks (Figure 2), was assessed through visual estimation and comprised approximately 40% rocks, 35% gravel, and 25% sand. All rivers were characterized by clear water, strong currents, and substrates dominated by rocks, gravel, and sand, providing suitable habitats for feeding, spawning, and juvenile development.

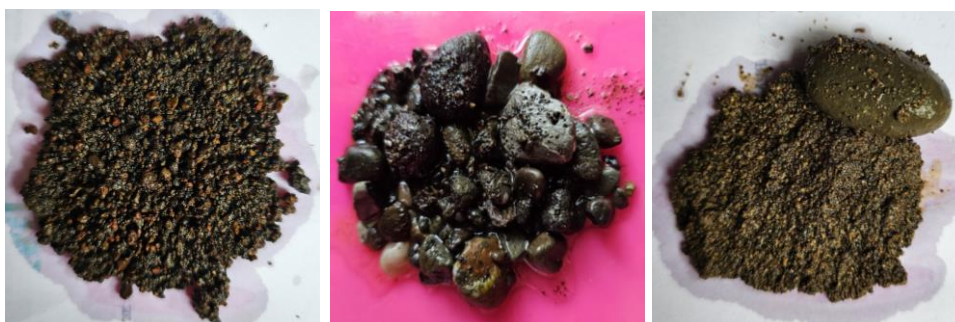


Figure 2. Dominant riverbed substrate types recorded at the sampling sites (from left to right: gravel, rock, and sand). These substrate characteristics contribute to habitat heterogeneity and provide important microhabitats for mahseer (*Tor* sp.) populations in the studied river systems.

The number of fish caught at each research site varied in terms of individual count, body length, and weight (Table 2). A total of 74 mahseer individuals (*Tor* sp.) were collected from four river systems in Central Java, namely the Pelus, Tutung Gunung, Comal, and Welo rivers. Two species were identified, *T. tambra* and *T. Tambroides* (Figure 3), although their distribution varied among sampling locations, with specimens measuring 3.7-29.2 cm in total length. The highest catch was recorded in the Pelus River, with a total of 39 individuals, whereas the lowest catch was observed in the Tutung Gunung and Welo rivers, with only 8 individuals each.

Table 2  
Number of *Tor* sp. individuals caught at Pelus River, Tutung Gunung River, Comal River, and Welo River, Central Java, Indonesia

Locations	Number of fish	Fish weight (g)	Fish length (cm)	Species
Pelus River, Banyumas	10	2.09-23.95	6.2-13.9	<i>Tor tambra</i>
	29	0.82-30.90	3.80-15.70	<i>Tor tambroides</i>
Tutung Gunung River, Purbalingga	8	0.80-88.42	4.20-22.10	<i>Tor tambroides</i>
Comal River, Pemalang	10	0.69-348.01	3.70-29.20	<i>Tor tambra</i>
	9	1.62-42.52	5.50-16.50	<i>Tor tambroides</i>
Welo River, Pekalongan	8	22.5-234.2	13.5-27.7	<i>Tor tambra</i>

The Pelus River exhibited the highest number of collected specimens ( $n = 39$ ), consisting of 10 individuals of *T. tambra* and 29 individuals of *T. tambroides*. Specimens of *T. tambra* from this river ranged from 2.09 to 23.95 g in body weight and from 6.2 to 13.9

cm in total length. In contrast, *T. tambroides* showed a broader size range, with body weights varying between 0.82 and 30.90 g and total lengths between 3.8 and 15.7 cm. In the Tutung Gunung River, all collected specimens were identified as *T. tambroides* (n = 8). This population exhibited considerable variation in body size, with weights ranging from 0.80 to 88.42 g and total lengths ranging from 4.2 to 22.1 cm. The Comal River contained both species, with 10 individuals of *T. tambra* and 9 individuals of *T. tambroides*. Among all sampling locations, the largest specimen was recorded in this river, where *T. tambra* reached a maximum body weight of 348.01 g and a total length of 29.2 cm. Meanwhile, *T. tambroides* specimens weighed between 1.62 and 42.52 g and measured 5.5–16.5 cm in total length. The Welo River was represented exclusively by *T. tambra* (n = 8). Individuals collected from this river were generally larger than those from the Pelus River, with body weights ranging from 22.5 to 234.2 g and total lengths ranging from 13.5 to 27.7 cm.

Overall, *T. tambroides* was more abundant than *T. tambra*, accounting for 46 of the 74 collected specimens (62.2%). *T. tambroides* was recorded in three river systems (Pelus, Tutung Gunung, and Comal), whereas *T. tambra* was found in the Pelus, Comal, and Welo rivers. The Pelus River supported the largest number of individuals, while the Tutung Gunung and Welo rivers each contributed eight specimens to the dataset.



Figure 3. Representative mahseer species (*Tor tambroides* on the left; *Tor tambra* on the right) collected across the four research locations.

The Comal River and the Pelus River exhibited the highest diversity, with both *T. tambra* and *T. tambroides* present in various size classes, while the Tutung Gunung River was inhabited exclusively by *T. tambroides*, and the Welo River by *T. tambra*. The high abundance in the Comal River is likely influenced by strong local conservation practices. Communities in the upstream areas actively protect the river ecosystem by prohibiting destructive fishing methods such as poisoning, electrocution, and netting. Instead, traditional fishing techniques like angling and hand nets are employed. Certain river sections, known locally as "river banks", are preserved as critical habitats for spawning, larval development, and feeding, thereby supporting the sustainability of *Tor* sp. populations. Similar to the Comal River, the Pelus River also supported the coexistence of *T. tambra* and *T. tambroides*, indicating relatively favorable habitat conditions and ecological stability. In contrast, lower abundance in the Tutung Gunung and Welo Rivers may be attributed to higher fishing pressure, particularly through the use of fishing rods, nets, and "ngregem" (catching fish with hands) at night which can disrupt population stability and habitat integrity.

**Biodiversity of mahseers.** Mahseer biodiversity differed among the four studied rivers, as shown in Table 3. The Comal River exhibited the highest diversity with a Shannon–Wiener index of 0.69, indicating a relatively balanced composition of *T. tambra* and *T. tambroides*. The Pelus River showed moderate diversity ( $H' = 0.57$ ), although *T. tambroides* was more dominant than *T. tambra*. In contrast, the Tutung Gunung and Welo Rivers each contained only a single species, resulting in a Shannon diversity index of zero. These findings indicate that the species diversity of mahseer is unevenly distributed across the upstream rivers surrounding Mount Slamet.

Table 3

Biodiversity index of mahseer (*Tor* sp.) populations in Pelus River, Tutung Gunung River, Comal River, and Welo River

River	<i>Tor tambra</i> (n)	<i>Tor tambroides</i> (n)	Total (N)	Shannon index (H')	Simpson index (1-D)
Pelus River	10	29	39	0.57	0.38
Tutung Gunung River	0	8	8	0.00	0.00
Comal River	10	9	19	0.69	0.50
Welo River	8	0	8	0.00	0.00

The data revealed low diversity and uneven distribution of *T. tambra* and *T. tambroides* across the four investigated river systems. Species composition varied spatially, with Pelus and Comal rivers supporting two *Tor* species, while Tutung Gunung and Welo rivers were characterized by the occurrence of a single species only. Such spatial heterogeneity suggests that local habitat conditions and river connectivity play a pivotal role in structuring *Tor* species assemblages in Java.

**Amino acids composition of mahseers.** Mahseer (*Tor* sp.) from at Pelus River, Tutung Gunung River, Comal River, and Welo River exhibited a complete amino acid composition. Among essential amino acids, lysine was the most abundant component at all locations, ranging from 11.52% to 13.81% of total amino acids, with the highest level recorded in fish from Welo River. Leucine was the second most dominant essential amino acid (5.85-6.92%), while moderate levels of threonine, valine, and phenylalanine were consistently observed across all sites. For non-essential amino acids, glutamic acid was the predominant component (12.21-16.31%), followed by aspartic acid, alanine, and tyrosine. The highest arginine content was observed in fish from Tutung Gunung (8.74%) (Table 4).

Amino acids composition of Mahseer (*Tor* sp.) varied among locations while showing consistent nutritional patterns. Amino acid analysis revealed dominance of non-essential amino acids (55.74-61.80%), with essential amino acids contributing 33.61-39.04% across locations (Table 5). Mahseer collected from Welo River showed the highest total EAA content (39.04%) and a high total amino acid concentration (95.54%), suggesting superior protein quality at this site. Samples from Pelus River and Tutung Gunung River also displayed balanced amino acid profiles, with EAA contents of approximately 37.79% and 37.84%, respectively. Notably, Tutung Gunung River mahseer exhibited the highest NEAA proportion (61.80%) and the highest total amino acid concentration (99.64%).

Based on amino acid composition data from the four research locations, a descriptive analysis of total essential amino acids (EAA) and non-essential amino acids (NEAA) was conducted. The results showed differences in nutritional composition between locations.

The essential (EAA) and non-essential amino acid (NEAA) composition of mahseer (*Tor* sp.) varied among the studied locations, indicating differences in protein nutritional quality that are likely influenced by environmental and dietary factors. Overall, mahseer from all locations exhibited a high proportion of essential amino acids, confirming the species as a valuable source of high-quality dietary protein.

Table 4

Amino acids composition of *Tor* sp. from various research locations

Amino acids	Content (% total amino acids)			
	Pelus River	Welo River	Comal River	Tutung Gunung River
<i>Essential amino acids</i>				
Histidine	2.12	2.41	1.87	1.69
Threonine	3.63	3.88	3.47	4.15
Methionin	2.39	2.29	1.24	2.30
Valin	3.08	3.24	3.37	3.20
Phenylalanin	3.63	3.50	3.38	3.78
Isoleucine	2.82	3.03	2.91	2.95
Leucine	6.78	6.88	5.85	6.92
Lysine	13.34	13.81	11.52	12.85
<i>Non-essential amino acids</i>				
Glutamic acid	14.16	14.52	12.21	16.31
Alanine	8.63	8.01	6.94	10.01
Arginine	6.09	6.60	5.82	8.74
Tyrosine	8.66	8.70	7.34	8.79
Aspartic acid	9.58	9.58	8.26	10.59
Serine	4.44	4.50	3.60	5.56
Glycine	4.18	4.59	5.00	9.80

Table 5

Essential and non-essential amino acid composition of mahseer (*Tor* sp.) from different locations

Locations	Total essential amino acid (%)	Total non-essential amino acid (%)	Total amino acids (%)
Pelus River	37.79	55.74	93.53
Welo River	39.04	56.50	95.54
Comal River	33.61	49.17	82.78
Tutung Gunung River	37.84	61.80	99.64

**Fatty acids composition of mahseers.** The fatty acid profile of mahseer (*Tor* sp.) consisted of both saturated fatty acids (SFA) and unsaturated fatty acids (UFA), with proportions varying among sampling locations. Methyl arachidate was the dominant SFA (11.81-19.94%), with the highest level recorded in fish from Comal River, followed by methyl heptadecanoate (1.71-4.47%) and methyl myristate (1.93-4.22%). Monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA) were mainly represented by methyl linolelaidate (27.61-29.46%) and methyl palmitoleate (18.61-21.18%), making them the major contributors to the total UFA fraction. In addition, omega-3 fatty acids were detected, including eicosapentaenoic acid (EPA; 0.10-0.28%) and docosahexaenoic acid (DHA; 3.26-7.46%), with the highest DHA content observed in fish from Welo River (7.46%) (Table 6).

The fatty acid composition of mahseer (*Tor* sp.) collected from four different locations showed a clear predominance of unsaturated fatty acids over saturated fatty acids in all sampling sites. Overall, unsaturated fatty acids accounted for approximately 63.63-71.80% of total identified fatty acids, while saturated fatty acids represented about 28.17-36.36%, indicating a nutritionally favorable lipid profile (Table 7).

The proportion of saturated fatty acids varied among locations, ranging from 28.17% in Welo River to 36.36% in Comal River. Fish from Comal River exhibited the highest SFA content (36.36%), followed by Pelus River (35.53%) and Tutung Gunung River (33.68%), whereas Welo River samples showed the lowest percentage of saturated fatty acids. Unsaturated fatty acids dominated the lipid profile of mahseer in all studied locations, accounting for 64.46% in Pelus River, 66.32% in Tutung Gunung River, 63.63% in Comal River, and reaching the highest level in Welo River (71.80%). This pattern highlights the richness of mahseer lipids in biologically and nutritionally valuable unsaturated fatty acids.

Table 6

Fatty acids content of *Tor* sp. from different locations

Fatty acids	Content (% of fatty acids)			
	Pelus River	Tutung Gunung River	Comal River	Welo River
<i>Saturated fatty acids</i>				
Methyl butyrate	<0.1	<0.1	<0.1	<0.1
Methyl hexanoate	<0.1	<0.1	<0.1	<0.1
Methyl octanoate	<0.1	<0.1	<0.1	<0.1
Methyl decanoate	<0.1	0.13	0.23	<0.1
Methyl undecanoate	<0.1	<0.1	<0.1	<0.1
Methyl laurate	1.75%	4.51	5.42	0.42
Methyl tridecanoate	<0.1	<0.1	<0.1	<0.1
Methyl myristate	1.93	4.22	3.56	2.07
Methyl pentadecanoate	<0.1	0.17	0.48	<0.1
Methyl palmitate	<0.1	<0.1	0.40	<0.1
Methyl heptadecanoate	4.47	3.51	1.71	4.28
Methyl stearate	<0.1	0.65	<0.1	0.54
Methyl arachidate	18.70	14.42	19.94	11.81
Methyl heneicosanoate	3.04	2.09	0.31	4.24
Methyl tricosanoate	3.87	2.60	3.75	2.83
Methyl lignocerate	1.77	1.38	0.56	1.98
<i>Unsaturated fatty acids</i>				
Myristoleic acid methyl ester	0.40	0.18	<0.1	0.40
Methyl cis-10-pentadecenoate	<0.1	0.25	0.47	0.32
Methyl palmitoleate	18.61	21.18	20.22	19.84
Methyl cis-10-heptadecenoate	0.16	0.44	0.36	0.59
Methyl trans-9-elaidate	<0.1	<0.1	<0.1	<0.1
Methyl cis-9-oleate	8.71	8.14	7.69	8.54
Methyl linoleaidate	28.20	29.46	27.61	29.40
Methyl linoleate	<0.1	<0.1	<0.1	<0.1
gamma-Linolenic acid methyl ester	<0.1	<0.1	<0.1	<0.1
Methyl cis-11-eicosenoate	<0.1	<0.1	1.82	<0.1
Methyl linolenate	0.21	0.30	0.33	0.12
Methyl cis-11,14-eicosadienoate	1.28	1.19	<0.1	4.06
Methyl docosanoate+	<0.1	<0.1	<0.1	<0.1
Methyl cis-8,11,14-eicosatrienoate				
Methyl cis-11,14,17-eicosatrienoate	0.77	0.29	0.45	<0.1
Methyl erucate	0.17	<0.1	<0.1	<0.1
Methyl cis-5,8,11,14-eicosatetraenoate	0.80	0.53	0.88	0.51
Methyl cis-13,16-docosadienoate	<0.1	<0.1	<0.1	<0.1
Methyl cis-5,8,11,14,17-eicosapentaenoate	0.17	0.13	0.10	0.28
Methyl nervonate	0.81	0.59	0.44	0.28
Methyl cis-4,7,10,13,16,19-docosahexaenoate	4.17	3.64	3.26	7.46

Table 7

Proportions of saturated and unsaturated fatty acids in mahseer (*Tor* sp.) from different locations

Locations	SFA ( $\Sigma$ saturated fatty acids, %)	UFA ( $\Sigma$ unsaturated fatty acids, %)	Total fatty acids (%)
Pelus River	35.53	64.46	99.99
Tutung Gunung River	33.68	66.32	100.00
Comal River	36.36	63.63	99.99
Welo River	28.17	71.80	99.97

## Discussion

**The ecological characteristics.** The physicochemical parameters of water quality across the four research sites were relatively consistent (Table 1). The environmental parameters recorded across the four upstream river sites were within the optimal tolerance range for *Tor* sp. survival and development (Amanda et al 2023). Among these parameters, temperature, DO, and pH are particularly critical, as they play a fundamental role in regulating fish biodiversity and population dynamics in freshwater ecosystems (Sarkar & Saha 2021; Tecklie 2024).

Water temperature measurements across the study sites indicated conditions conducive to the survival of *Tor* sp. The highest temperature was recorded in the Comal River ( $25.0 \pm 2.0^\circ\text{C}$ ), while the lowest was observed in the Pelus River ( $22.5 \pm 2.0^\circ\text{C}$ ). The relatively lower temperature in the Pelus River is likely due to limited light penetration caused by dense riparian vegetation. These findings are consistent with Desrita et al (2019), who reported that the optimal temperature range for *Tor* sp. lies between  $24.73$  and  $25.53^\circ\text{C}$ . Additionally, Akhtar & Ciji (2023) noted that *Tor* sp. thrives within a broader temperature range of  $15$ - $25^\circ\text{C}$ , further supporting the suitability of the observed conditions.

The DO levels measured at all study sites were within the suitable range for the survival of *Tor* sp. The highest DO concentration was recorded in the Tutung Gunung River ( $8.3 \pm 0.4 \text{ mg L}^{-1}$ ), while the lowest was observed in the Comal River ( $7.4 \pm 0.3 \text{ mg L}^{-1}$ ). These values indicate good water quality, as higher DO levels are typically associated with fast-flowing waters that enhance oxygenation. According to Haryono & Subagja (2008), *Tor* sp. require DO levels above  $5 \text{ mg L}^{-1}$  for optimal physiological function, and all observed sites met this criterion.

The pH values across the research locations also fell within the optimal range for *Tor* sp. The highest pH was recorded in the Tutung Gunung River ( $7.9 \pm 0.2$ ), and the lowest in the Comal River ( $7.7 \pm 0.4$ ). These values are consistent with the suitable pH range of  $6.5$ - $8.5$  as reported by Haryono & Subagja (2008), indicating that the aquatic environment in all study sites supports the species' survival and development.

In terms of water quality, ammonia and nitrite concentrations measured in the Pelus River, Tutung Gunung, Comal River, and Welo River were relatively low and remained below the threshold levels considered detrimental to *Tor* sp. These results suggest that the physicochemical conditions of the study sites are favorable for the species' survival and growth, corroborating the findings of Haryono & Subagja (2008).

Water current velocity ranged from  $2.6$  to  $4.6 \text{ m s}^{-1}$ , categorizing these rivers as fast-flowing habitats. This condition is favorable for *Tor* sp., which prefers moderate to strong currents, particularly during juvenile and subadult stages (Desrita et al 2019; Abass et al 2024). The observed water depths, ranging from  $30$  to  $110 \text{ cm}$ , are also suitable for small to medium-sized *Tor* sp., which typically inhabit shallow river sections (Haryono & Subagja 2008).

Substrate composition at the bottom of the Pelus, Tutung Gunung, Comal, and Welo Rivers consisted of large rocks, gravel, and sand. Such substrate types are ideal for *Tor* sp., providing essential microhabitats for spawning, nursery, and feeding activities (Haryono & Subagja 2008; Akhtar & Ciji 2023; Mulyani et al 2023; Abass et al 2024). The geological characteristics of the riverbeds in the Pelus, Tutung Gunung, Comal, and Welo Rivers revealed substrates composed of eroded volcanic rocks, including basalt, andesite, gravel, and sand. These rock types are consistent with the geological composition of Mount Slamet, which comprises basaltic andesites, pumice, and pyroclastic deposits with relatively high  $\text{SiO}_2$  content (Prasetya & Gibran 2024). Such substrate conditions are highly favorable for *Tor* sp., particularly for spawning, as fertilized eggs require clean water and stable substrates for attachment (Akhtar & Ciji 2023).

Field observations revealed a high abundance of natural food sources at the study sites, including aquatic insects, stone worms, and mosses. These dietary components were identified both in the surrounding environment and within the digestive tracts of captured *Tor* species, indicating active foraging behavior. This observation is consistent

with findings by Amanda et al (2023) and Abass et al (2024), who reported that *Tor* species predominantly consume small insects and periphyton attached to submerged rocks. Furthermore, Tiwari et al (2025) demonstrated that *T. tor* exhibits considerable dietary plasticity, feeding on phytoplankton, zooplankton, protozoa, and detritus depending on seasonal availability.

The present study demonstrates that both the Comal and Pelus Rivers serve as important habitats for *Tor* sp., as evidenced by the presence of *T. tambra* and *T. tambroides* across a wide range of sizes and numbers (Table 2). The observed population structure, with overlapping size distributions and the presence of both juveniles and adults, suggests that these rivers provide suitable conditions for multiple life stages. Such habitat suitability is typically associated with key environmental factors, including adequate water depth, high DO, moderate flow velocity, and the presence of natural substrates such as boulders and cobbles. However, differences in the size range and abundance between rivers may reflect variations in local habitat quality, resource availability, or the degree of anthropogenic disturbance (Patil & Saxena 2021; Dhawan et al 2023).

In contrast, only *T. tambroides* was found in the Tutung Gunung River, while only *T. tambra* was recorded in the Welo River. This pattern of single-species occurrence at certain sites is likely a result of the limited sampling focus on *Tor* species diversity, rather than reflecting true habitat segregation between the two species. Both *T. tambra* and *T. tambroides* are generally known to occupy similar riverine habitats, typically preferring clear, fast-flowing waters with substrates composed of rocks, gravel, and sand (Haryono & Subagja 2008; Pinder et al 2019; Akhtar & Ciji 2023; Amanda et al 2023).

Previous studies have reported that these species often coexist in the same river systems and exhibit overlapping ecological requirements, including water quality, flow velocity, and substrate type. The absence of one species at a particular site in this study may therefore be attributed to local population fluctuations, sampling effort, or stochastic factors, rather than distinct habitat preferences. Overall, the results do not suggest significant habitat partitioning between *T. tambra* and *T. tambroides*, as both species are rheophilic and associated with undisturbed, oxygen-rich river stretches with rocky substrates. This finding is consistent with previous reports indicating that *Tor* species, including *T. tambra* and *T. tambroides*, are highly dependent on the availability of pristine river habitats and are sensitive to environmental disturbances (Jaafar et al 2021; Lau et al 2021).

The ecological conditions observed in the Pelus, Tutung Gunung, Comal, and Welo Rivers, located at the foot of Mount Slamet, characterized by fast-flowing, clear water, high DO, and rocky, gravelly, and sandy substrates are consistent with the preferred habitat of mahseer (Desrita et al 2019; Pinder et al 2019; Atifah et al 2021; Yuhana et al 2021). These environments support critical life stages such as spawning and juvenile development, which are highly sensitive to degradation. In such natural settings, mahseer exhibit upstream migration behavior during major flood events at the onset of the rainy season, seeking submerged areas for spawning. Spawning typically occurs one to two months after flooding, in calm, clear river sections with sandy or coral substrates (Desrita et al 2019).

These findings are consistent with observations in other regions, such as the upper reaches of the Wampu River in Sumatra, which have been identified as suitable habitats for *Tor* sp. (Desrita et al 2019). Similarly, Atifah et al (2021) reported that *T. tambra* is commonly found in the upper reaches of rivers within tropical forest ecosystems, particularly in mountainous areas. In Indonesia, this species is widely distributed across Sumatra, Java, and Kalimantan, predominantly inhabiting fast-flowing river systems.

**Biodiversity of mahseers.** The variation in mahseer biodiversity across the four rivers is likely driven by a combination of ecological conditions, habitat connectivity, and anthropogenic pressures, which collectively shape freshwater fish assemblages (Reid et al 2019; Dudgeon 2020). Rivers such as the Comal and Pelus, which support both *T. tambra* and *T. tambroides*, may provide relatively stable and heterogeneous habitats that

facilitate the coexistence of multiple mahseer species through niche differentiation and resource partitioning (Pinder et al 2019; Lau et al 2021). The relatively balanced species composition observed in the Comal River, as reflected by its high Shannon diversity index (Shannon 1948), indicates a more stable ecological condition and higher habitat quality (Magurran 2021). Such characteristics suggest that the Comal River may function as an important refuge habitat, providing favorable environmental conditions that support the persistence and resilience of *Tor* populations in the Mount Slamet region (IUCN 2018; Mulyani et al 2023).

In contrast, the Tutung Gunung and Welo Rivers supported only a single *Tor* species, resulting in very low species diversity. Such patterns are commonly associated with ecological constraints and historical population processes, where environmental filtering limits species coexistence (Kraft et al 2015; Magurran 2021). River fragmentation, localized fishing pressure, and environmental variability can reduce species coexistence and cause one species to dominate certain habitats (Grill et al 2019; Pinder et al 2019). In addition, localized fishing pressure and environmental variability can further exacerbate these effects, favoring the dominance of more tolerant species (Reid et al 2019). These patterns are consistent with observations in other tropical river systems, where the diversity of mahseer (*Tor* sp.) is heavily influenced by habitat integrity and hydrological connectivity (Jaafar et al 2021).

The biodiversity patterns observed in this study are consistent with the ecological characteristics of the four rivers. Fast-flowing waters with coarse, rocky substrates and high DO concentrations are known to support rheophilic fishes, including *Tor* species, which are adapted to such high-energy environments (Pinder et al 2019; Dudgeon 2020; Akhtar & Ciji 2023; Amanda et al 2023). However, even small variations in environmental parameters, when combined with anthropogenic disturbances, can significantly influence species distribution and relative abundance (Desrita et al 2019; Reid et al 2019; Atifah et al 2021). Rivers characterized by greater substrate heterogeneity and more stable flow regimes tend to provide suitable spawning grounds and feeding habitats, thereby supporting the coexistence of multiple species (Haryono & Subagja 2008; Amanda et al 2023; Dhawan et al 2023). Such habitat complexity is widely recognized as a key driver of biodiversity in riverine ecosystems, promoting niche differentiation and enhancing community stability (Patil & Saxena 2021).

Dominance patterns inferred from Simpson's index (Simpson 1949) corroborate this view. Moderate dominance values in the Pelus ( $1-D = 0.38$ ) and Comal Rivers ( $1-D = 0.50$ ) suggest communities composed of two species with unequal population sizes, a pattern commonly associated with partial environmental filtering (Magurran 2021). In contrast, dominance values approaching zero in the Tutung Gunung and Welo Rivers indicate strong monopolization by a single species, reflecting more restrictive ecological conditions. Such dominance structures are characteristic of freshwater systems where environmental constraints limit species coexistence (Kraft et al 2015; Dudgeon 2020). This pattern is particularly evident in mahseer (*Tor* sp.), which are highly dependent on specific habitat conditions, including fast-flowing, well-oxygenated waters, coarse rocky-gravel substrates, and high water clarity (Haryono & Subagja 2008; Pinder et al 2019). These environmental characteristics strongly influence species occupancy, performance, and ultimately the structure of fish communities in riverine ecosystems (Kottelat et al 2018; Lau et al 2021).

Shannon diversity ( $H'$ ) values were low across all sampling sites (0.00-0.69), reflecting limited species richness and low community evenness (Shannon 1948; Magurran 2021). In ecological interpretation,  $H'$  values below 1 generally indicate very low diversity and simplified community structure, often characterized by strong species dominance and restricted niche availability (Krebs 1999). Such patterns are commonly observed in lotic ecosystems dominated by specialized rheophilic taxa, where strong environmental filtering associated with flow regime and habitat structure limits species coexistence (Poff et al 1997; Matthews 1998). In freshwater systems, reduced diversity is frequently linked to habitat constraints or disturbance legacies, including anthropogenic impacts that alter hydrology and habitat quality (Reid et al 2019; Dudgeon 2020). This is particularly relevant for mahseer (*Tor* sp.), which exhibit strong habitat specialization and

are therefore sensitive to environmental changes (Pinder et al 2019). The highest  $H'$  in the Comal River (0.69) coincided with the coexistence of *T. tambra* and *T. tambroides* at more balanced relative abundances, underscoring the central role of evenness in shaping alpha diversity metrics (Arif et al 2025). Conversely, the absence of diversity in Tutung Gunung and Welo ( $H' = 0.00$ ) is attributable to a single species state and zero evenness, which is also captured by Simpson's index ( $1-D = 0.00$ ) indicating absolute dominance (Roswell et al 2021).

Differences in biodiversity among rivers are plausibly linked to variation in habitat complexity and longitudinal connectivity (Shao et al 2019). Rivers with wider channels and a diverse mosaic of microhabitats (e.g., pools, riffles, and runs) provide a greater range of ecological niches that facilitate species coexistence (Matthews 1998; Tockner et al 2006). In contrast, smaller and more fragmented headwater systems tend to restrict interspecific interactions and often favor single-species dominance due to limited habitat availability (Dudgeon 2020). These patterns are consistent with the life history traits of mahseer (*Tor* sp.), which rely on longitudinal connectivity for seasonal migrations related to feeding and spawning (Kottelat et al 2018; Pinder et al 2019). In Central Java, earlier field studies similarly documented low mahseer diversity and fragmented populations in mountain streams, reinforcing that limited connectivity and narrow habitat breadth constrain *Tor* assemblages at the catchment scale (Arif et al 2025).

The absence of species coexistence in the Tutung Gunung and Welo Rivers may be associated with limited habitat heterogeneity, narrower channel width, and reduced longitudinal connectivity. Small headwater streams with simplified habitat structure often restrict niche availability and promote competitive exclusion, resulting in single-species dominance (Dudgeon 2020). Mahseer (*Tor* sp.) are known to undertake seasonal longitudinal migrations for spawning and feeding, and disruption of these movements can lead to spatial segregation or local exclusion of less competitive species (Kottelat et al 2018; Pinder et al 2019; Lau et al 2021). In contrast, larger and more structurally complex rivers such as the Pelus and Comal Rivers likely provide a broader range of microhabitats, including pools, riffles, and transitional zones, which enhance niche diversity and facilitate species coexistence (Matthews 1998; Tockner et al 2006).

Anthropogenic pressures, including land use change, sedimentation, and overexploitation, are key drivers of freshwater biodiversity loss, with land cover alterations explaining substantial variation in fish species richness in river systems (Blackman et al 2021; Zhang et al 2025). These stressors have been shown to significantly reduce freshwater fish diversity worldwide (Deng et al 2024; Liu et al 2025), including in Indonesian rivers where human-induced habitat modification and fragmentation lead to marked declines in species richness along upstream-downstream gradients (Wibowo et al 2025). Recent studies combining environmental DNA and conventional surveys further demonstrate that fish biodiversity patterns are strongly structured by longitudinal gradients and pollution intensity, with downstream areas typically exhibiting reduced diversity due to habitat degradation (Gao et al 2025; Liu et al 2025). Such patterns highlight the high sensitivity of rheophilic fishes, including mahseer (*Tor* sp.), to cumulative anthropogenic stressors, particularly those affecting river connectivity and flow regimes (Lau et al 2021; Syafrialdi & Amrullah 2025; Wibowo et al 2025).

The findings of this study are consistent with previous investigations on mahseer biodiversity in Central Java and other Indonesian river systems, which have reported relatively low diversity indices and highlighted the fragmented nature of *Tor* populations in mountainous and sub-mountainous streams (Haryono & Subagja 2008; Muchlisin et al 2022). On a broader scale, mahseer (*Tor* sp.) are widely recognized as indicator species of riverine ecosystem health due to their high sensitivity to habitat alteration, flow regulation, and water quality degradation (IUCN 2018; Pinder et al 2019). Freshwater fish assemblages are known to respond rapidly to anthropogenic disturbances, with reduced diversity often reflecting declining ecological integrity and increasing environmental stress (Reid et al 2019; Lau et al 2021; Su et al 2021). Therefore, the low diversity observed in the studied rivers may indicate early signs of ecological degradation within these freshwater systems (Arif et al 2025).

From a conservation perspective, the dominance of single species and low diversity values suggest that *Tor* populations in the studied rivers are potentially vulnerable to stochastic events and environmental change (Lau et al 2021). Conservation strategies should prioritize habitat protection in the upper reaches, maintenance of river connectivity, and regulated fishing practices, particularly during spawning migrations. Additionally, domestication and restocking programs based on local genetic stocks have been proposed as complementary approaches to sustain declining *Tor* populations, provided that genetic integrity is carefully maintained (Marnis et al 2024; Himawan et al 2026).

**Amino acids composition of mahseers.** The essential (EAA) and non-essential amino acid (NEAA) composition of mahseer (*Tor* sp.) varied among the studied locations, indicating differences in protein nutritional quality. Such variability is consistent with previous studies showing that amino acid composition in fish is influenced by species-specific characteristics, habitat conditions, and dietary inputs, which collectively determine the nutritional value of fish protein (Chasanah et al 2021; Das et al 2024; Azrita et al 2024; Khan et al 2024; Nurfaidah et al 2024; Traina et al 2024). Overall, mahseer from all locations exhibited a high proportion of essential amino acids, confirming the species as a valuable source of high quality dietary protein.

Mahseer collected from Welo River showed the highest total EAA content (39.04%) and total amino acid concentration (95.54%), suggesting superior protein quality at this site. A high proportion of essential amino acids is nutritionally important, as these indispensable amino acids cannot be synthesized by the human body and must be obtained through dietary intake (Church et al 2020; Paoletti et al 2024; Burstad et al 2025). Similar findings have been reported in mahseer and other freshwater fish, where elevated EAA levels are associated with improved growth performance and favorable nutritional attributes (Bhatt & Pandit 2016; Das et al 2024).

Samples from Pelus River and Tutung Gunung River also displayed balanced amino acid profiles, with EAA contents of 37.79% and 37.84%, respectively. Notably, Tutung Gunung River mahseer exhibited the highest NEAA proportion (61.80%) and the highest total amino acid concentration (99.64%). High NEAA levels, such as glutamic acid, aspartic acid, and glycine (commonly reported in freshwater fishes), contribute to palatability, metabolic functions, and nitrogen balance in muscle tissue, enhancing both nutritional and sensory quality of the flesh (Lise et al 2021; Jayadi et al 2022; Azrita et al 2024).

In contrast, mahseer from Comal River recorded the lowest total amino acid concentration (82.78%) and the lowest EAA proportion (33.61%). This comparatively reduced amino acid content may reflect differences in food availability, energy allocation, or habitat conditions. Previous studies on freshwater fish have demonstrated that amino acid composition is strongly influenced by feeding ecology, water quality, and habitat productivity, which can vary substantially among river systems (Všetičková et al 2019; Chasanah et al 2021; Das et al 2024; Azrita et al 2024; Khan et al 2024; Shapawi et al 2025).

Fish is widely recognized as an important source of high-quality protein and essential fatty acids for human nutrition. The presence of essential amino acids such as lysine and leucine in high proportions indicates the superior nutritional quality of fish protein (Mohanty et al 2019; Das et al 2024). Recent studies on freshwater fish species also demonstrate that variations in amino acid composition among populations are closely associated with dietary sources and ecological conditions of river ecosystems (Azrita et al 2024; Khan et al 2024).

The amino acid profile of *Tor* sp. indicates a complete spectrum of essential and non essential amino acids, with lysine consistently predominating among essentials and glutamic acid among non essentials across sites. Such patterns are typical of freshwater food fishes, in which lysine and leucine are usually among the highest essential amino acids, while glutamic and aspartic acids dominate the non essential fraction and contribute to umami taste and overall sensory quality (Nurfaidah et al 2024). Lysine's prominence aligns with its recognized role as a first limiting amino acid for growth and

protein accretion in many cultured finfish and with requirement ranges summarized by the NRC (2011). The relatively high leucine is consistent with its function as both a structural amino acid and a regulator of protein synthesis via TOR/mTOR signaling in teleosts, which is linked to growth and tissue development (Zhao et al 2020; Wang et al 2026). Elevated glutamic acid, together with aspartic acid and alanine, is frequently reported in fish muscle and is associated with nitrogen metabolism and umami attributes in fish products (Ryu et al 2021; Das et al 2024).

Site to site differences in amino acid composition are plausible given environmental and dietary contrasts; recent field and lab studies show that habitat, diet composition, and even gut microbiome structure co vary with metabolic capacities in cyprinids, potentially altering amino acid pools in muscle (Liu et al 2022). From a human nutrition standpoint, the observed spectrum of essentials (including lysine, leucine, threonine, valine, and phenylalanine) is comparable to profiles reported for diverse riverine fishes and can contribute meaningfully to meeting recommended dietary allowances when consumed regularly (Das et al 2024).

**Fatty acids composition of mahseers.** The proportion of saturated fatty acids varied among sampling locations, with the highest contribution observed in Comal River (36.36%), followed by Pelus River (35.53%) and Tutung Gunung River (33.68%), while Welo River exhibited the lowest SFA content (28.17%). Long chain saturated fatty acids dominated the SFA fraction, especially methyl arachidate, which was consistently the most abundant saturated fatty acid at all sites. Similar dominance of long chain SFAs has been reported in other mahseer species and cyprinid fishes, where palmitic, stearic, and arachidic acids often constitute a large proportion of total SFA (Kovacik et al 2025; Shapawi et al 2025).

Variations in SFA content among locations may be attributed to differences in environmental conditions, natural diet, and metabolic characteristics of mahseer populations inhabiting distinct river systems. According to Všeticková et al (2019), fatty acid profiles in freshwater fish are strongly influenced by geographical location, food availability, season, and habitat characteristics. Despite these variations, the overall SFA content in mahseer from all locations remained lower than UFA content, reinforcing their favorable lipid profile.

Unsaturated fatty acids were the predominant lipid class in mahseer across all locations, accounting for 64.46% in Banyumas, 66.32% in Purbalingga, 63.63% in Pemalang, and reaching the highest proportion in Pekalongan (71.80%). This dominance of UFAs is characteristic of freshwater fish and reflects the important physiological role of unsaturated fatty acids in maintaining membrane fluidity and metabolic regulation (Taşbozan & Gökçe 2017).

Monounsaturated fatty acids (MUFA), particularly palmitoleic and oleic acid methyl esters, contributed substantially to the unsaturated fatty acid fraction, while polyunsaturated fatty acids (PUFA), including linoleic, linolenic, eicosapentaenoic (EPA), and docosahexaenoic acid (DHA) methyl esters, were present at moderate but nutritionally significant levels; although EPA and DHA concentrations in freshwater fish are generally lower than in marine species, their presence is widely recognized for important health benefits, especially in cardiovascular protection and neural development (Parzanini et al 2020; Shoeb et al 2022; Sprague et al 2026).

The fatty acid composition shows both SFA and UFA with clear spatial variation, a pattern widely attributed to differences in natural diet (plankton/benthos), habitat conditions, season, and life stage (Gonçalves et al 2012). The dominance of certain SFAs (e.g., C20:0 methyl arachidate equivalent in FAME reports) is consistent with the role of SFAs as energy substrates and membrane forming lipids in fish tissues; classic and current reviews emphasize that the balance of SFA, MUFA, and PUFA reflects both trophic inputs and endogenous metabolism (Zhang et al 2020; Li et al 2023; Liu et al 2024). Among UFAs, the high proportions of specific C18 and C16 species (e.g., methyl linolelaidate as the trans isomer of 18:2n 6 and palmitoleate 16:1n 7) indicate strong dietary and metabolic signatures; palmitoleate is a common MUFA biosynthesized via

stearoyl-CoA desaturase (SCD) activity and variably abundant in fish tissues, although actual levels depend on diet and species (Všetičková et al 2019; Tocher 2015).

The presence of omega 3 LC PUFA - EPA and especially DHA - supports both ecological and nutritional inferences. In freshwater systems, fish EPA/DHA typically trace back to algal (epilithic/periphytic) PUFA either directly via diet or indirectly through selective retention and enzymatic elongation/desaturation from C18 precursors; field data show fish tissues often mirror algal, not terrestrial, PUFA sources (Ebm et al 2021; Yan et al 2024). Foundational work in fish lipid nutrition likewise notes that freshwater and diadromous species can utilize C18 PUFA to meet part of their needs, while dietary supply and environmental context shape tissue EPA/DHA levels (Tocher 2010). Controlled studies in cyprinids confirm that dietary lipid class and source modulate muscle EPA/DHA and up regulate HUFA biosynthesis genes ( $\Delta 6$  Fad, Elovl5) when long chain n 3 intake is low, explaining inter site variation in LC PUFA in wild fish (Ren et al 2020).

Within mahseer specifically, experimental work on *T. tambroides* demonstrates that dietary lipid level and the balance between saturated and n 3 fatty acids influence growth performance and tissue fatty acid composition, and suggests potential "n 3 sparing" by SFA under certain formulations - mechanisms that may contribute to the patterns observed across locations in wild *Tor* sp. (Ng & Andin 2011; Ramezani-Fard et al 2012). Recent comparative data from Borneo mahseer (*Tor douronensis*) further indicate that habitat management (e.g., tagal conservation) can shift both amino acid totals and fatty acid classes, reinforcing the role of environment and diet in shaping fillet quality (Shapawi et al 2025).

From a human health perspective, the recorded DHA levels (up to ~7.5%) are notable. Omega 3 LC PUFA support membrane fluidity and cellular signaling, and remain a focus of cardiovascular and neurocognitive research; authoritative reviews and meta analyses report benefits on triglycerides and selected cardiovascular outcomes, with some heterogeneity between EPA only and EPA+DHA trials (Djuricic & Calder 2025). Newer syntheses and randomized controlled trials refine the picture, highlighting dose/form and apolipoprotein E genotype effects on brain delivery and mixed outcomes for major events, but overall support roles in membrane function and potential neuroprotection (Arellanes et al 2020; María et al 2024). Additional 2024 reviews emphasize omega 3 contributions to erythrocyte membrane fluidity and broader physiological effects, which align mechanistically with the presence of DHA/EPA in *Tor* tissues (Capece et al 2024).

Ecologically, differences among sites likely reflect basal resource availability (algae vs. detritus/terrestrial input), benthic/planktonic prey composition, and local environmental stressors, all of which are known drivers of fish lipid profiles (Hu et al 2024). Bayesian meta analysis across aquaculture species also shows that freshwater/omnivorous fishes exhibit higher tolerance to reduced dietary n 3 LC PUFA supply while still modulating tissue levels, insightful when interpreting wild population variability (Wu et al 2024).

**Relationship between amino acids and fatty acids profiles in mahseer.** The combined analysis of amino acid composition (essential and non-essential amino acids) and fatty acid composition (saturated and unsaturated fatty acids) demonstrates that mahseer (*Tor* sp.) from all studied locations possesses high nutritional quality, characterized by a favorable balance of protein and lipid components. Essential amino acids (EAAs) constitute a substantial proportion of total amino acids, confirming the high biological value of mahseer protein (Khan et al 2024; Shapawi et al 2025). Furthermore, unsaturated fatty acids (UFAs) consistently predominate over saturated fatty acids (SFAs), indicating a lipid profile associated with health benefits (FAO 2020). These findings collectively confirm that mahseer is a nutrient-dense freshwater fish with significant dietary and functional value.

Mahseer from Welo River exhibited the most desirable combined profile, showing the highest proportion of UFA (71.80%) alongside the highest EAA content (39.04%). This co-occurrence suggests a convergence of high-quality lipids and proteins, indicating superior nutritional value. Long-chain polyunsaturated fatty acids (PUFAs), particularly

EPA and DHA, are known to play essential roles in cellular metabolism, membrane structure, and physiological regulation in fish (Tocher 2015; Prananda et al 2025). These fatty acids contribute to membrane fluidity and metabolic efficiency, which may enhance nutrient utilization, including protein metabolism (Calder 2017). Therefore, their higher abundance in mahseer from Welo River may be associated with improved amino acid retention and muscle protein quality.

Inter-location differences (e.g., lower UFA and lower EAA in Comal River relative to Welo River) are plausibly driven by environmental and dietary factors that shape both lipid and protein accretion in fish. Reviews on freshwater fish consistently document that geographical location, habitat conditions, natural diet, seasonality, and reproductive status modulate fatty-acid composition and, by extension, can covary with amino-acid profiles and total nitrogenous constituents of muscle (Hussain et al 2018; Vřetičková et al 2019). These context effects have also been observed specifically in mahseer, where habitat and management system (wild vs. no-take) significantly influence lipid classes and fatty-acid totals (Shapawi et al 2025).

Samples from Pelus River and Tutung Gunung River showed balanced nutritional characteristics, with UFA proportions exceeding 64% and EAA contents close to 38%. Tutung Gunung River mahseer, despite having slightly lower UFA than Welo River, displayed the highest total amino acid content, mainly due to elevated non-essential amino acids (NEAA). High levels of non-essential amino acids (NEAAs), particularly glutamic acid and aspartic acid, play crucial roles in metabolic processes, nitrogen balance, and physiological functions in fish, including participation in transamination reactions and energy metabolism (Li et al 2020; Chuphal et al 2025). In mahseer (*Tor* sp.), these amino acids are consistently reported as dominant components of muscle protein, with glutamic acid and aspartic acid occurring at high concentrations in both wild and cultured populations (Khan et al 2024; Shapawi et al 2025). These amino acids are well known for their contribution to sensory properties, especially the umami taste, which is primarily associated with glutamate and aspartate in fish flesh (Lise et al 2021; Miftachurrochmah et al 2025). Furthermore, the overall amino acid richness of mahseer, influenced by habitat and diet, indicates its high nutritional value and potential consumer preference (Shapawi et al 2025). Therefore, mahseer from Tutung Gunung River may also possess favorable nutritional and sensory characteristics (Dogan et al 2017; Hu et al 2022).

In contrast, mahseer from Comal River recorded the lowest UFA proportion (63.63%) and the lowest total amino acid and EAA contents, indicating comparatively lower nutritional value. This pattern suggests that environmental factors such as food availability, habitat productivity, and energy allocation play a significant role in regulating lipid metabolism and protein deposition in fish (Prananda et al 2025; Shapawi et al 2025). Variations in fatty acid composition, particularly reduced UFA levels, are often associated with differences in diet and ecological conditions (Vřetičková et al 2019). These environmental influences may simultaneously affect amino acid composition and protein synthesis, leading to coordinated changes in lipid and protein profiles (Tocher 2015; Mohanty et al 2019). Similar co-variation patterns have been widely reported in freshwater fish species, highlighting the importance of habitat quality in shaping overall nutritional composition (FAO 2020; Khan et al 2024).

The integration of amino acid and fatty acid profiles suggests that higher proportions of unsaturated fatty acids (UFAs) are associated with increased levels of essential amino acids (EAAs), indicating a positive relationship between lipid quality and protein nutritional value (Mohanty et al 2019; Prananda et al 2025). From a human nutrition perspective, this combination is highly beneficial, as n-3 polyunsaturated fatty acids (PUFAs), such as EPA and DHA, are well known for their roles in cardiovascular and metabolic health (Tocher 2015; Calder 2017). Meanwhile, essential amino acids are critical for muscle protein synthesis, growth, tissue repair, and overall physiological function (Wolfe 2002).

Therefore, mahseer (*Tor* sp.) can be regarded as a high-quality freshwater protein source with health-promoting lipid characteristics (Mohanty et al 2019; Khan et al 2024). The presence of beneficial unsaturated fatty acids, particularly long-chain n-3 PUFAs,

further enhances its nutritional value and relevance for human health (Tocher 2015; Calder 2017). However, the nutritional composition of fish is strongly influenced by environmental conditions, including habitat quality and food availability (Všetičková et al 2019; Prananda et al 2025). These findings highlight the importance of habitat conservation and sustainable management of mahseer populations to maintain both ecological integrity and nutritional quality (FAO 2020; Marnis et al 2024).

### **Comparison of amino acids and fatty acids profiles among mahseer populations.**

The present study revealed that mahseer populations from the rivers surrounding Mount Slamet exhibit a nutritionally rich biochemical profile characterized by high levels of essential amino acids and unsaturated fatty acids. When compared with mahseer populations reported from India and the Himalayan region, several similarities and differences emerge that highlight the influence of ecological conditions, trophic resources, and evolutionary adaptation. The amino acid composition observed in Indonesian mahseer is broadly consistent with previous studies on Himalayan mahseer such as *Tor putitora*. Studies from Himalayan rivers reported that dominant amino acids in mahseer muscle include lysine, leucine, glutamic acid, and aspartic acid, indicating the high nutritional quality of this species (Sharma et al 2024).

Similarly, the present study found lysine and leucine to be among the most abundant essential amino acids in Indonesian mahseer populations. Lysine is particularly important for protein synthesis, growth, and tissue repair, and its abundance in mahseer indicates that the species provides high-quality dietary protein. Comparable findings were reported in mahseer populations from the Himalayan region, where lysine and leucine were identified as dominant essential amino acids contributing to the high nutritional value of the fish (Chasanah et al 2021).

In addition to essential amino acids, non-essential amino acids such as glutamic acid and aspartic acid were found to be highly abundant in both Indonesian and Himalayan mahseer populations (Chasanah et al 2021; Sharma et al 2024). These amino acids play important roles in nitrogen metabolism and contribute to the characteristic umami flavor of fish flesh. The dominance of glutamic acid in mahseer tissues has also been documented in Himalayan populations, further confirming the similarity in protein composition among geographically distant mahseer species (Sharma et al 2024).

Despite these similarities, some differences can also be observed. For example, studies on Indonesian mahseer (*Tor soro*) reported that the amino acid profile may also include relatively high concentrations of phenylalanine and allo-isoleucine depending on habitat conditions and feeding ecology (Chasanah et al 2021). These variations likely reflect differences in diet composition and environmental productivity among river systems.

Furthermore, studies on Malaysian mahseer (*T. tambroides*) demonstrated that this species possesses enzymatic pathways capable of converting precursor fatty acids into long-chain polyunsaturated fatty acids such as EPA and DHA, suggesting that mahseer species have metabolic flexibility in lipid biosynthesis (Sam et al 2021).

**Conclusions.** The upstream rivers at the foot of Mount Slamet represent ecologically suitable habitats for mahseer (*Tor* sp.), as reflected by favorable water quality, fast-flowing conditions, and rocky-gravel substrates that are consistent with the habitat requirements of *Tor tambra* and *Tor tambroides*. However, biodiversity patterns varied among rivers, with species coexistence occurring only in Pelus and Comal Rivers, while Tutung Gunung and Welo Rivers were characterized by single-species dominance, indicating the influence of habitat heterogeneity, river connectivity, and local disturbance on population structure.

Mahseer from all sampling locations exhibited complete amino acid profiles and nutritionally favorable fatty acid compositions, confirming their value as high-quality freshwater fish. Essential amino acids contributed substantially to total amino acids, and unsaturated fatty acids predominated over saturated fatty acids, including nutritionally important omega-3 fatty acids (EPA and DHA). Spatial variation in nutritional quality, with the most favorable profiles observed in Welo River and comparatively lower values in

Comal River, suggests that local habitat productivity and food availability affect protein and lipid deposition in mahseer muscle tissue. Overall, the findings demonstrate a clear linkage between upstream habitat conditions, biodiversity patterns, and nutritional quality of mahseer populations.

**Authors Contributions.** S: conceptualization, methodology, investigation, writing – original draft; IP: data analysis, visualization, writing – review and editing; HM: supervision, validation, and manuscript revision.

**Conflicts of Interest.** The authors declare that there is no conflict of interest.

**Data Availability.** The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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## References

- Abass Z., Shah T. H., Bhat F. A., Ramteke K., Magloo A. H., Hamid I., Wanjari R. N., Somasundharam I., 2024 The mahseer: the tiger of water - an angler's delight in the Himalayas and the undisputed king of sport fishing. *Fisheries Research* 279: 107147.
- Akhtar M. S., Ciji A., 2023 The endangered mighty mahseer (*Tor putitora*) in the Himalayan waters. In: *Fisheries and aquaculture of the temperate Himalayas*. Pandey P. K., Pandey N., Akhtar M. S. (eds), Springer, Singapore, pp. 81-94.
- Akmal Y., Muliari M., Humairani R., Zulfahmi I., Burhanuddin A. I., Budimawan B., Batubara A. S., 2022 Species authentication of *Tor* spp. (family Cyprinidae) in Indonesia based on osteocranium structure and biometric data. *Zoologischer Anzeiger* 299:21-30.
- Amanda L., Prakoso V. A., Boer M., Wildan D. M., Kurniawan K., Rochman F., Iswanti A., Irawan D., Jaya Y. Y. P., Rosadi I., Sudarsono S., Wibowo A., 2023 Food and feeding habits of *Tor tambra* (Valenciennes, 1842) in Cibareno River, West Java, Indonesia. *E3S Web of Conferences* 442:01015.
- AOAC, 2003 Official methods of analysis of the Association of Official Analytical Chemists. 17th edition. Association of Official Analytical Chemists, Washington, DC. USA.
- Arellanes I. C., Choe N., Solomon V., He X., Kavin B., et al., 2020 Brain delivery of supplemental docosahexaenoic acid (DHA): a randomized placebo-controlled clinical trial. *eBioMedicine* 59:102883.
- Arif S. N., Suwarsito, Pratama I., 2025 [Morphological analysis and biodiversity of dewa fish (*Tor* sp.) in the Pelus River and Tutung Gunung River, Central Java]. *Sainteks* 22(2):167-180. [in Indonesian]
- Atifah Y., Achyar A., Sumarmin R., 2021 Population of tambra fish (*Tor tambra*) in Batang Gadis River Mandailing Natal North Sumatra. *Journal of Physics: Conference Series* 1940:012067.
- Azrita A., Syandri H., Zakeri H. A., Damanhuri H., Aryani N., 2024 Analysis of fatty acids and amino acids of three local freshwater Bagridae fish species in the Kampar Kanan River, Indonesia, for food security. *International Journal of Food Science* 2024:6639837.
- Bhatt J. P., Pandit M. K., 2016 Endangered golden mahseer *Tor putitora* Hamilton: a review of natural history. *Reviews in Fish Biology and Fisheries* 26:25-38.
- Blackman R. C., Osathanunkul M., Brantschen J., Di Muri C., Harper L. R., Mächler E., Hänfling B., Altermatt F., 2021 Mapping biodiversity hotspots of fish communities in subtropical streams through environmental DNA. *Scientific Reports* 11:10375.

- Burstad K. M., Lamina T., Erickson A., Gholizadeh E., Namigga H., Claussen A. M., Slavin J. L., Teigen L., Gallant K. M. H., Stang J., Steffen L. M., Harindhanavudhi T., Kouri A., Duval S., Butler M., 2025 Evaluation of dietary protein and amino acid requirements: a systematic review. *The American Journal of Clinical Nutrition* 122(1):285-305.
- Calder P. C., 2017 Omega-3 fatty acids and inflammatory processes: from molecules to man. *Biochemical Society Transactions* 45(5):1105-1115.
- Capece U., Gugliandolo S., Morciano C., Avolio A., Splendore A., Di Giuseppe G., Ciccarelli G., Soldovieri L., Brunetti M., Mezza T., Pontecorvi A., Giaccari A., Cinti F., 2024 Erythrocyte membrane fluidity and omega-3 fatty acid intake: current outlook and perspectives for a novel, nutritionally modifiable cardiovascular risk factor. *Nutrients* 16(24):4318.
- Chasanah E., Fithriani D., Poernomo A., Jeinie M. H., Huda N., 2021 The nutritional profile of Indonesian salmon van Java mahseer *T. soro* species. *Potravinarstvo Slovak Journal of Food Sciences* 15:566-574.
- Chuphal N., Malik M. A., Kishore P. S., Mohanta K. N., 2025 Amino acids as functional nutrients in stress mitigation of aquatic species: mechanisms and applications in aquaculture. *Blue Biotechnology* 2:20.
- Church D. D., Hirsch K. R., Park S., Kim I. Y., Gwin J. A., Pasiakos S. M., Wolfe R. R., Ferrando A. A., 2020 Essential amino acids and protein synthesis: insights into maximizing the muscle and whole-body response to feeding. *Nutrients* 12(12):3717.
- Das B. K., Ganguly S., Bayen S., Talukder A. K., Ray A., Gupta S. D., Kumari K., 2024 Amino acid composition of thirty food fishes of the Ganga riverine environment for addressing amino acid requirements through fish supplementation. *Foods* 13(13):2124.
- Deng J., Zhang X., Yao X., Rao J., Dai F., Wang H., Wang Y., Jiang W., 2024 eDNA metabarcoding reveals differences in fish diversity and community structure in Danjiang River. *Scientific Reports* 14:29460.
- Desrita, Tamba I. S., Muhtadi A., Ariyanti J., Leidonald R., 2019 Diversity and habitat condition of *Tor* fish (*Tor* spp.) in the upstream of Wampu waters, North Sumatra, Indonesia. *IOP Conference Series Earth and Environmental Science* 260:012102.
- Dhawan B., Sivakumar K., Johnson J. A., 2023 Habitat suitability of golden mahseer young ones (*Tor putitora*, Hamilton 1822) in Himalayan waters, India. *River Research and Application* 39(10):1950-1960.
- Djuricic I., Calder P. C., 2025 N-3 fatty acids (EPA and DHA) and cardiovascular health - updated review of mechanisms and clinical outcomes. *Current Atherosclerosis Reports* 27(1):116.
- Doğan G., Ertan Ö. O., 2017 Determination of amino acid and fatty acid composition of goldband goatfish [*Upeneus moluccensis* (Bleeker, 1855)] fishing from the Gulf of Antalya (Turkey). *International Aquatic Research* 9:313-327.
- Dudgeon D., 2020 *Freshwater biodiversity: status, threats and conservation*. Cambridge University Press, 514 pp.
- Ebm N., Guo F., Brett M. T., Bunn S. E., Kainz M. J., 2021 Polyunsaturated fatty acids in fish tissues more closely resemble algal than terrestrial diet sources. *Hydrobiologia* 848:371-383.
- FAO, 2020 *The state of world fisheries and aquaculture 2020: sustainability in action*. FAO, Rome, 244 pp.
- Gao J., Zhang J., Pan C., Xu S., Wu Y., Lv W., Hong M., Hu Y., Wang Y., 2025 Assessing fish diversity in the Chishui River using environmental DNA (eDNA) metabarcoding. *Fishes* 10(6):279.
- Gonçalves A. M. M., Azeiteiro U. M., Pardal M. A., De Troch M., 2012 Fatty acid profiling reveals seasonal and spatial shifts in zooplankton diet in a temperate estuary. *Estuarine, Coastal and Shelf Science* 109:70-80.
- Grill G., Lehner B., Thieme M., Geenen B., Tickner D., Antonelli F., Babu S., Borrelli P., Cheng L., Crochetiere H., et al., 2019 Mapping the world's free-flowing rivers. *Nature* 569:215-221.

- Haryono H., Subagja J., 2008 The population and habitat of tambra fish, *Tor tambroides* (Bleeker, 1854) in Muller Mountain waters, Central Kalimantan. *Biodiversitas* 9(4): 306-309.
- Himawan Y., Arifin O. Z., Subagja J., 2026 Development of freshwater *Tor* sp. in Indonesia: domestication and culture. In: *Aquaculture development in archipelago*. Nugroho E., Imron, Gunadi B., Rosmiati, Syahputra K. (eds), Springer, Singapore, pp. 91-98.
- Hu Y., Xiao N., Ye Y., Shi W., 2022 Fish proteins as potential precursors of taste-active compounds: an *in silico* study. *Journal of the Science of Food and Agriculture* 102(14):6404-6413.
- Hu Y., Yan L., Hu P., Guo H., Li X., Su W., 2024 Exploring the correspondence between benthic algae and changes in the aquatic environment for biodiversity development. *Sustainability* 16(24):11287.
- Hussain B., Sultana T., Sultana S., Ahmed Z., Mahboob S., 2018 Study on impact of habitat degradation on proximate composition and amino acid profile of Indian major carps from different habitats. *Saudi Journal of Biological Sciences* 25(4): 755-759.
- International Union for Conservation of Nature (IUCN), 2018 The IUCN Red List of Threatened Species.
- Jaafar F., Na-Nakorn U., Srisapoome P., Amornsakun T., Duong T. Y., Gonzales-Plasus M. M., Hoang D. H., Parhar I. S., 2021 A current update on the distribution, morphological features, and genetic identity of the Southeast Asian Mahseers, *Tor* species. *Biology* 10(4):286.
- Jayadi, Ilmiah, Rustam, Asni A., Nursyahrani, 2022 The amino acid profiles of *Telmatherina bonti* from Lake Towuti, South Sulawesi, Indonesia. *AAFL Bioflux* 15(6):2992-2998.
- Khan A. K., Zahid M., Rehman A. U., Khan R. A., 2024 Assessment of fatty acid composition and amino acid profiles of three important freshwater fish species native to River Indus Pakistan. *Brazilian Journal of Biology* 84:e286429.
- Kottelat M., Pinder A., Harrison A., 2018. *Tor tambroides*. The IUCN Red List of Threatened Species. e.T187939A9107655.
- Kovacik A., Helczman M., Arvay J., Jambor T., Kovacikova E., 2025 Toxic elements and fatty acid composition in the freshwater fish family Cyprinidae (Rafinesque 1815): balancing nutritional benefits and health risks. *Environmental Monitoring and Assessment* 197(6):676.
- Kraft N. J. B., Adler P. B., Godoy O., James E. C., Fuller S., Levine J. M., 2015 Community assembly, coexistence and the environmental filtering metaphor. *Functional Ecology* 29(5):592-599.
- Krebs C. J., 1999 *Ecological methodology*. 2nd edition. Benjamin Cummings, Menlo Park, 620 pp.
- Lau M. M. L., Lim L. W. K., Ishak S. D., Abol-Munafi A. B., Chung H. H., 2021 A review on the emerging Asian aquaculture fish, the Malaysian mahseer (*Tor tambroides*): current status and the way forward. *Proceedings of the Zoological Society* 74(2): 227-237.
- Li C., Lin H., Guo Y., Yu G., Ma Z., Pei K., Qin C., 2023 Fatty acid analysis reveals the trophic interactions among organisms in the Zhelin Bay Marine Ranch. *Frontiers in Marine Science* 10:1132246.
- Li X., Zheng S., Wu G., 2020 Nutrition and metabolism of glutamate and glutamine in fish. *Amino Acids* 52(5):671-691.
- Lise C. C., Marques C., Bonadimann F. S., Pereira E. A., Mitterer-Daltoé M. L., 2021 Amino acid profile of food fishes with potential to diversify fish farming activity. *Journal of Food Science and Technology* 58(1):383-388.
- Liu Y., Li X., Li Y., Li J., Zhu S., 2022 Gut microbiomes of cyprinid fish exhibit host-species symbiosis along gut trait and diet. *Frontiers in Microbiology* 13:936601.
- Liu Y., Li X., Chen W., Feng G., Chen F., Li J., Zhou Q., 2024 High-throughput sequencing and fatty acid profile analyses of the Black Amur bream (*Megalobrama terminalis*) reveal variation in dietary niche associated with geographic segregation. *Ecology and Evolution* 14(4):e11226.

- Liu Z., Wu Y., You W., Li S., Shi G., Zhang C., 2025 Revealing the structure and biodiversity patterns of fish communities in river networks based on environmental DNA. *Fishes* 10(4):175.
- Magurran A. E., 2021 Measuring biological diversity. *Current Biology* 31(19):1174-1177.
- María L. L., Vázquez R. F., Bellini M. J., Zamora R. A., Redondo-Morata L., Giannotti M. I., Oliveira Jr. O. N., Fanani M. L., Maté S. M., 2024 Understanding the effects of omega-3 fatty acid supplementation on the physical properties of brain lipid membranes. *iScience* 27(7):110362.
- Marnis H., Syahputra K., Darmawan J., Febrianti D., Tahapari E., Larashati S., Iswanto B., Primanita E. P. H., Syaifudin M., Subangkit A. T., 2024 DNA barcoding of fish diversity from Batanghari River, Jambi, Indonesia. *Fisheries and Aquatic Science* 27(2):87-99.
- Matthews W. J., 1998 *Patterns in freshwater fish ecology*. Springer, New York, 756 pp.
- Miftachurrochmah A., Sunarharum W. B., Fibrianto K., 2025 Traditional fermented fish 'bekasam' as a flavor enhancer: perspectives on characteristics of fermented product and sensory properties. *Journal of Ethnic Foods* 12:40.
- Mohanty B. P., Mahanty A., Ganguly S., Mitra T., Karunakaran D., Anandan R., 2019 Nutritional composition of food fishes and their importance in providing food and nutritional security. *Food Chemistry* 293:561-570.
- Muchlisin Z. A., Nur F. M., Maulida S., Handayani L. S., Rahayu S. R., 2022 Mahseer, the history of the king of the river. *E3S Web of Conferences* 339:03006.
- Mulyani I., Putra R. M., Sumiarsih E., Lesmana I., Syahrian W., 2023 [Population and suitable environmental conditions for the life of gadih fish (*Tor tambroides* Bleeker, 1854) in the upper Kampar Kanan River]. *Berkala Perikanan Terubuk* 51(1):1828-1834. [in Indonesian]
- Naik A. K., Mahata A., Palita S. K., 2024 First record two species of *Tor* mahseer in the Indravati River system of Godavari Basin of Eastern Ghats in Odisha, India, and conservation strategies. *Asian Journal of Conservation Biology* 13(1):105-117.
- Ng W. K., Andin V. C., 2011 The Malaysian mahseer, *Tor tambroides* (Bleeker), requires low dietary lipid levels with a preference for lipid sources with high omega-6 and low omega-3 polyunsaturated fatty acids. *Aquaculture* 322-323:82-90.
- National Research Council (NRC), 2011 *Nutrient requirements of fish and shrimp*. National Academies Press, Washington, DC, 376 pp.
- Nurfaidah, Asikin A. N., Kasmianti, Angraeni, 2024 Amino acid profile and potential utilization purposes of albumin from four types of freshwater fish in Makassar, South Sulawesi, Indonesia. *Biodiversitas* 25(11):4199-4207.
- Odum E. P., 1993 [Fundamental of ecology]. Gadjah Mada University Press, 697 pp. [in Indonesian]
- Paoletti A., Courtney-Martin G., Elango R., 2024 Determining amino acid requirements in humans. *Frontiers in Nutrition* 11:1400719.
- Patil N., Saxena S., 2021 A preliminary study on habitat ecology of mahseer (*Tor tor* Hamilton) in western zone of Narmada river and its tributaries. *International Journal of Innovation Research in Technology* 8(4):629-637.
- Parzanini C., Colombo S. M., Kainz M. J., Wacker A., Parrish C. C., Arts M. T., 2020 Discrimination between freshwater and marine fish using fatty acids: ecological implications and future perspectives. *Environmental Reviews* 28(4):546-559.
- Pinder A. C., Britton J. R., Harrison A. J., Nautiyal P., Bower S. D., Cooke S. J., Lockett S., Everard M., Katwate U., Ranjeet K., Walton S., Danylchuk A. J., Dahanukar N., Raghavan R., 2019 Mahseer (*Tor* spp.) fishes of the world: status, challenges and opportunities for conservation. *Reviews in Fish Biology and Fisheries* 29:417-452.
- Poff N. L., Allan J. D., Bain M. B., Karr J. R., Prestegard K. L., Richter B. D., Sparks R. E., Stromberg J. C., 1997 The natural flow regime. *BioScience* 47(11):769-784.
- Prananda M. R., Andriani Y., Pratiwy F. M., Iskandar, Haetami K., Zidni I., Herman R. G., 2025 The role and function of fatty acids in feed on fish growth. Peran dan fungsi asam lemak dalam pakan terhadap pertumbuhan ikan. *Jurnal Perikanan dan Kelautan* 30(1):18-23.

- Prasetya Y. A., Gibran A. K., 2024 [Old Mount Slamet and young Mount Slamet geology: a study of geomorphology, petrology, geotourism, and geological hazards]. *Jurnal Geosaintek* 10(1):71-84. [in Indonesian]
- Ramezani-Fard E., Kamarudin M. S., Saad C. R., Harmin S. A., Meng G. Y., 2012 Dietary lipid levels affect growth and fatty acid profiles of Malaysian mahseer *Tor tambroides*. *North American Journal of Aquaculture* 74(4):530-536.
- Reid A. J., Carlson A. K., Creed I. F., Eliason E. J., Gell P. A., Johnson P. T. J., Kidd K. A., MacCormack T. J., Olden J. D., Ormerod S. J., Smol J. P., Taylor W. W., Tockner K., Vermaire J. C., Dudgeon D., Cooke S. J., 2019 Emerging threats and persistent conservation challenges for freshwater biodiversity. *Biological Reviews* 94(3):849-873.
- Ren H. T., Zhang G. Q., Huang Y., Gao X. C., 2020 Effects of different dietary lipid sources on fatty acid composition and gene expression in common carp. *Czech Journal of Animal Science* 65(2):51-57.
- Roesma D. I., Chornelia A., Mursyid A., Kamsi M., 2016 Fish diversity of the Batang Toru river system, South Tapanuli, North Sumatra. *Biodiversitas* 17(2):628-634.
- Roswell M., Dushoff J., Winfree R., 2021 A conceptual guide to measuring species diversity. *Oikos* 130(3):321-338.
- Ryu B., Shin K. H., Kim S. K., 2021 Muscle protein hydrolysates and amino acid composition in fish. *Marine Drugs* 19(7):377.
- Sam K. K., Merosha P., Janaranjani M., Athirah I., Shu-Chien A. C., 2021 The Malaysian mahseer, *Tor tambroides* possess all required biosynthesis enzymes for the conversion of C18 polyunsaturated fatty acids to long-chain polyunsaturated fatty acids. *Aquaculture* 543:736942.
- Sarkar C., Saha N. C., 2021 Seasonal variation of water quality parameters and their impact on fish biodiversity indices of Hasadanga beel: a case study. *Current World Environment* 16(1):7-17.
- Shannon C. E., 1948 A mathematical theory of communication. *The Bell System Technical Journal* 27:379-423.
- Shao X., Fang Y., Jawitz J. W., Yan J., Cui B., 2019 River network connectivity and fish diversity. *Science of The Total Environment* 689:21-30.
- Shapawi R., Basri N. A., Seok-Kian A. Y., Seng L. L., Fui C. F., 2025 Nutritional profile comparison of wild and *tagal* indigenous mahseer (*Tor duoronensis*) from Borneo. *Sains Malaysiana* 54(1):1-8. [in Indonesian]
- Sharma A., Sarma D., Joshi R., Das P., Akhtar M. S., Pande V., Sharma P., 2024 Gonad indices, morphology and muscle fatty acid compositions of male and female golden mahseer (*Tor putitora*) sampled from lake Bhimtal (Himalaya) at different seasons of the year. *Aquaculture and Fisheries* 9(4):603-616.
- Shoeb M., Islam M. M., Tasnim K. T., Akter S., Mamun M. I. R., 2022 Lipid content and fatty acid profile of commonly consumed freshwater and marine fish of Bangladesh. *Current Research on Biosciences and Biotechnology* 4(1):256-261.
- Simpson E. H., 1949. Measurement of diversity. *Nature* 163:688.
- Sprague M., Betancor M. B., Rolland A., Tocher D. R., 2026 Evaluating the adequacy of current dietary guidelines for seafood as a source of long-chain omega-3 fatty acids. *Scientific Reports* 16:15190.
- Su G., Logez M., Xu J., Tao S., Villéger S., Brosse S., 2021 Human impacts on global freshwater fish biodiversity. *Science* 371(6531):835-838.
- Syafrialdi S., Amrullah M. Y., 2025 Diversity and conservation status of fish in Batang Bungo River, Bungo Regency, Jambi Province, Indonesia. *AAFL Bioflux* 18(2):888-902.
- Taşbozan O., Gökçe M. A., 2017 Fatty acids in fish. In: *Fatty acids*. Catala A. (ed). InTech, DOI: 10.5772/68048.
- Tecklie A. T., 2024 Species diversity, some biological aspects of fishes and water quality of Terie River, Beshilo Basin, Ethiopia. *Fisheries and Aquatic Sciences* 27(6):356-365.
- Tiwari P. K., Saxena S., Dubey S., 2025 Feeding ecology and dietary composition of mahseer (*Tor* spp.) in the Narmada River, Jabalpur District. *International Journal of Biology Science* 7(7):21-26.

- Tocher D. R., 2010 Fatty acid requirements in ontogeny of marine and freshwater fish. *Aquaculture Research* 41(5):717-732.
- Tocher D. R., 2015 Omega-3 long-chain polyunsaturated fatty acids and aquaculture in perspective. *Aquaculture* 449:94-107.
- Tockner K., Paetzold A., Karaus U., Claret C., Zettel J., 2006 Ecology of braided rivers. In: Braided rivers: process, deposits, ecology and management. Sambrook Smith G. H., Best J. L., Bristow C. S., Petts G. E. (eds), Special publication of the International Association of Sedimentologists No. 36, pp. 339-359.
- Traina A., Quinci E. M., Sabatino N., Del Core M., Bellante A., Bono G., Giuga M., Avellone G., Sprovieri M., D'Agostino F., 2024 Protein, essential amino acid, and fatty acid composition of five target fishery species of Central Mediterranean Sea. *Animals* 14(15):2158.
- Všetičková L., Suchý P., Straková E., 2019 Factors influencing the lipid content and fatty acids composition of freshwater fish: a review. *Asian Journal of Fisheries and Aquatic Research* 5(4):1-10.
- Wang S., Liu S., Zhang S., Lu S., Han S., Jiang H., Liu H., Wang C., 2026 Dietary leucine supplementation enhances growth performance, digestive enzyme activity, and intestinal barrier function in triploid rainbow trout (*Oncorhynchus mykiss*) fed plant-protein based diets. *Aquaculture Reports* 46:103324.
- Wibowo A., Kurniawan K., Prakoso V. A., Ginanjar R., Rochman F., Zamroni M., et al., 2025 Characterizing spatial patterns among freshwater fishes and shrimps of the Poso River (Sulawesi, Indonesia) using DNA barcoding. *Aquatic Sciences* 87:2.
- Wolfe R. R., 2002 Regulation of muscle protein by amino acids. *The Journal of nutrition* 132(10):3219-3224.
- Wu Y., Rashidpour A., Metón I., 2024 Bayesian meta-analysis: impacts of eating habits and habitats on omega-3 long-chain polyunsaturated fatty acid composition and growth in cultured fish. *Animals* 14(14):2118.
- Yan K., Guo F., Kainz M. J., Li F., Gao W., Bunn S. E., Zhang Y., 2024 The importance of omega-3 polyunsaturated fatty acids as high-quality food in freshwater ecosystems with implications of global change. *Biology Reviews* 99(1):200-218.
- Yuhana S., Hendriyanto D. A., Sitanggang M., 2021 [Mahseer aquaculture: a super freshwater fish with exceptional economic value]. *AgroMedia*, Jakarta, 120 pp. [in Indonesian]
- Zhang H., Blackman R. C., Furrer R., Osathanunkul M., Brantschen J., Di Muri C., Harper L. R., Hänfling B., Niklaus P. A., Pellissier L., Schaepman M. E., Zong S., Altermatt F., 2025 Terrestrial land cover shapes fish diversity in a major subtropical river catchment. *Communications Biology* 8:1113.
- Zhang X., Ning X., He X., Sun X., Yu X., Cheng Y., Yu R. Q., Wu Y., 2020 Fatty acid composition analyses of commercially important fish species from the Pearl River Estuary, China. *PLoS ONE* 15(1):e0228276.
- Zhao Y., Li J. Y., Jiang Q., Zhou X. Q., Feng L., Liu Y., Jiang W. D., Wu P., Zhou J., Zhao J., Jiang J., 2020 Leucine improved growth performance, muscle growth, and muscle protein deposition through AKT/TOR and AKT/FOXO3a signaling pathways in hybrid catfish *Pelteobagrus vachelli* × *Leiocassis longirostris*. *Cells* 9(2):327.

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