Research Square

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Impact of habitat types on growth pattern of Barbs from Northern Eastern Ghats of India

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Abstract

The research explores the effects of different habitat types on both the shape and growth of six species of barb fish (*Puntius* and *Pethia*) through the use of geometric morphometry and descriptions of length-weight relationships. Different hydrodynamic habitats (lentic and lotic) produced differences in the structural dimensions of the six species of barb fish; specifically, the lentic populations produced fishes that were generally deeper through the body than those from the lotic populations. This reflects the difference in stability of each habitat type. In general, the lentic populations displayed allometric growth, with b-values generally between 3.10 and 3.34, except negative growth relative to *Pethia conchonius*, with b-values of 2.34 and 1.37. The overall results of the relationship analysis produced a statistically significant correlation ($p < 0.05$), with with r ranging from 0.38 (*Pethia conchonius*) to 0.98 (*Puntius chola*) and R^2 from 0.14 to 0.97. In general, Fulton's condition factor (K) indicated that both populations were healthy; however, the K values of the lentic populations of Pethia exhibited weaker relationships. Overall, there were a number of biomechanical adaptations attributable to the specific habitat features which determine both morphology and growth of the six species of barb fish in this study. The study demonstrates that fish have adapted to their respective habitats and understanding this is important for conservation efforts of biodiversity and improving climate resilience in the many aquatic ecosystems of southern Odisha.

Introduction

The innate nature of living beings to adapt to the environment, helps in the growth of the individuals. Growth rate estimation, which might be attributed to increase in length/ weight or both (Seikh et al. 2017) acts as foundation stone for inspection on productivity and turnover rate (Wright 1983). Habitat parameters also impact the phenotypes of the organisms, and in turn provide an insight on the ecosystem health (Manoroma and Ramanujam 2014). In fishery science, the study of length- weight relation (LWR) in terms of total length of fish samples (Negi and Tyagi 2015) is an important aspect for estimation of production, growth, productivity of the habitat, stocking density, maturity of populations etc. (Deka and Gohain 2015). In the age of climate change, ideal environment condition is a myth, and as per Broody (1945) fishes grow isometrically under ideal environment condition, and any deviation from the Cube's Law (Le Cren 1951) points out deviation from the ideal condition of hydrology (Kalita et al. 2017). Moreover, in case of aquatic environment, the high spatial and temporal dynamicity also influences the body shape, as an adaptation to the flow velocity, hydrometric drag (Foster et al. 2014). Thus, habitat variation leads to the adaptation of the divergent phenotypes (Langerhans 2008) giving rise to morphologically divergent populations in heterogenous environment (Hendry et al. 2002; Langerhans 2008; Franssen 2011).

"Barbs" under Cyprinidae family (Cypriniformes) is a catch all genus mainly comprising of five genus i.e. *Puntius*, *Pethia*, *Systomus*, *Dravida* and *Dawkinsia* (Pethiyagoda et al. 2012). This group is widely distributed in South-East Asia particularly throughout India, Nepal, Bangladesh, Sri Lanka, Mayamar, Thailand, the Malayan Archipelago, and Southern China. Barbs are economically important in terms of

their ornamental, food and medicinal value (Choudhury et al. 2011). Among fishes, barbs are important in terms of their taxonomic ambiguity (Hora and Mukerji 1934; Smith 1945; Myers 1960), which arises from their phenotypic plasticity (Myers 1960; Stearns 1983) of sharing of morphological traits (Choat et al. 1996).

Barbs are abundantly distributed in a variety of habitats such as lakes, ditches, ponds, rivers, and hill-streams (Santakumar and Viswanath 2006), playing an important role in trophic dynamics (Weliange and Amarasinghe 2003). Consequently, variations in their abundance or assemblage structure effectively indicate habitat degradation, water-quality fluctuations, and fragmentation, underscoring their role as bioindicators in freshwater ecosystem monitoring and conservation management (Saroniya 2021). Barbs also play an important ecological role in freshwater energy fluxes, facilitating the transfer and recycling of organic matter between primary producers, benthic decomposers, and higher trophic levels by feeding upon periphytic algae, macrophytes, aquatic invertebrates, and detrital matter. Such trophic versatility enables them to function as key intermediaries, which enhances their ecological resilience and adaptive capacity within fluctuating aquatic environments (Saroniya 2021).

Owing to their taxonomical, economical, as well as ecological importance, barbs act as a valuable model because of their climate responsive activity (Brown et al. 2024). Their distribution across diverse microhabitats makes them highly susceptible to local disturbances such as pollution, hydrological alteration, and habitat degradation, with changes in their abundance, body shape, or growth patterns providing early warnings of ecosystem stress. At the same time, ecological plasticity renders them responsive to broader climate-driven pressures, including rising temperatures, altered flow regimes, and shifts in food availability (Barbarossa et al. 2021).

Quite a good number of studies on length- weight relationship of freshwater species have been carried out from different parts of India, from River Jhelum, Kashmir (Bhat et al. 2016), three north-Indian rivers Gomti, Ganga and Ken (Kashyap et al. 2017; Singh and Serajuddin 2017), Central Brahmaputra Valley, Assam (Nath et al. 2019). However, in Odisha majority of length-weight relation study has been carried out on marine and estuarine fishes (Karna and Panda 2012; Karna et al. 2012, Parida et al. 2013, Mohanty and Nayak 2017, Mohanty et al. 2014 etc.). However such studies on LWR are limited in Eastern Ghats, which could have highlighted the aquatic health condition, as growth of fish species is particularly impacted by aquatic habitat.

Koraput (18.8135° N, 82.7123° E), located in the southern Odisha, part of northern Eastern Ghats, is a region of landscape diversity in terms of both terrestrial and aquatic habitat, harbouring a large variety of faunal diversity. The barb species have been recorded to be widely distributed in freshwater bodies of Koraput (Surachita and Palita 2022) and barbs are a part of the daily diet of the local inhabitants of the region. In the present study LWR of six barb species under genus Puntius (*Puntus sophore, Puntius amphibius*, *Puntius dorsalis* and *Puntius chola*,) and Pethia (*Pethia ticto* and *Pethia conchonius*) have been analysed in order to understand, whether variations in habitat conditions exerts a significant influence on the growth trajectories and morphological configurations of freshwater barbs or not as, populations in

lentic habitats are predicted to show positive allometric growth with deeper body forms due to stable hydrodynamic conditions, whereas those in lotic habitats are expected to exhibit more streamlined morphologies shaped by continuous flow-related selective pressures.

Methods

Collection of samples

Populations of six barb species (*Puntius sophore, Puntius amphibius, Puntius dorsalis, Pethia chola, Pethia ticto and Pethia conchonius*) representing lentic and lotic habitat were studied. Samples were collected from three stretches of Kolab river at Dudhari (18º43′21.99"N; 82º57′20.84"E), Upar Borabandha (18º38′52.07"N; 82º58′51.13"E and Ghatguda (18º45′39"N; 82º49′0.98"E) constituting the lotic bodies and Jagannath Sagar (19º8′50.39"N; 82º18′43.49"E) and Damayanti Sagar (18º51′29.59"N; 82º33′45.11"E) constituting the lentic water body (Fig. 1). Dudhari is a 1st order stream located at an elevation of887m ASL, with a depth of 0.713 m and average velocity of 0.63 m/sec. Upar Borabandha is a 1st order stream, located at 934 m ASL, with an average depth of 0.8 m and velocity of 1.32 m/sec. Ghatguda is situated on the upper part of the Kolab Reservoir at an elevation of 858 m with an average depth of 1.19 m and a velocity of about 0.74 m/sec. However, the lentic water bodies (Damayanti Sagar and Jagannath Sagar) were located at an elevation of 574–593 m, with an average depth of 2m and a velocity of about 0.5 m/sec.

Length- weight relationship

For each species, a minimum of 30 individuals collected from lentic and lotic habitats were studied for growth analysis. The length was measured nearer to 0.1 mm total length (TL), with digital Vernier Calliper and weight was measured nearest to 0.1 g total weight (TW) using digital weighing balance. The relationship between the length and weight of the fish was calculated using the equation $W = a L^b$ (Le Cren 1951 and Froese 2006), which was converted to the linear regression equation of Log TW = log a + b log TL, where a and b are regression parameters. Fulton condition factor of the species (Fulton, 1904) was estimated using the equation $K = 100\ W/L^3$.

Geometric Morphometrics

For shape variation study, the images of all the samples in lateral view were taken using Canon EOS 80 D camera. Data was collected in the form of eleven (11) nos. of selected two-dimensional coordinate landmarks (Fig. 2). The description of 11 landmarks had been given (Imron et al. 2023) in Fig. 2. The landmark coordinates were digitized using applications tpsdig2 and tpsutil (Rohlf 2015).

Multivariate Analysis

Mean, standard deviation, range, and condition factor (K) for length and weight, of each species collected from different habitats were computed by using M.S. Excel Software (2010). Mean of Kn value

of fish species collected from both the habitat were subjected to two tailed t test by using XLSTAT. The p-value, when observed to be less than 0.05, showed significant variation. The mean value for length in weight for each species collected from different lentic and lotic habitats was subjected to PCA and Box Plot analysis by using PAST software, to show the variation in growth for the populations of each species. The data obtained from the landmarks were analysed to detect the shape alterations using Principal Component Analysis (PCA). The variation was displayed through a wire form graph and transformational grid. The analyses were done by using MorphoJ software, a combined package for geometric morphometry (Klingenberg 2011).

Results

Descriptive Statistics

A total of 492 specimens, comprising of four species each under Genus Puntius, *P. sophore* (n = 122), *P. amphibius* (n = 100), *P. dorsalis* (n = 54), *P. chola* (n = 54*)*, and two species under genus Pethia, *P. ticto* (n = 87) and *P. conchonius* (n = 75) from both lotic and lentic water bodies, were studied for length- weight relationship. The logarithmic regression equation, correlation coefficient (r), coefficient of determination (R2), and Fulton's condition factor had been given in Table 1, for the population of each species, from both the habitats.

In lentic water bodies, higher length and increased weight (Fig. 4) was observed in three species under Puntius genera, such as *P. sophore* (95.8 ± 11.23 mm; 12.60 ± 3.40 gm), *P. amphibius* (97.92 ± 7.23 mm; 13.25 ± 3.37 gm), *P. dorsalis* (84.08 ± 9.81mm; 7.97 ± 3.44 gm), and only one species under Pethia genera, i.e. *P. ticto* (53. 28 ± 2.99 mm; 2.87 ± 0.96 gm) in lentic habitat compared to the lotic water bodies (Table 1). However, two other species under genus Puntius and Pethia, i.e. *P .chola* (88.96 ± 10.84 mm; 9.50 ± 3.50 gm) and *P. conchonius* (56.02 ± 9.83 mm; 3.33 ± 0.76 gm) exhibited higher length and heavier body weight in lotic population compared to lentic (Table 1).

For the species like *P. amphibius* (b = 3.25), *P. dorsalis* (b = 3.19), *P. chola* (b = 3.15) and *P. ticto* (b = 3.34), the value of length exponent 'b' was recorded to be more in lentic populations showing positive allometric growth (b > 3), while lotic populations showed negative allometric growth (b < 3). *P. sophore* showed the positive allometric growth (b = 3.10) for the lotic population. *P.conchonius* showed negative allometric growth (b < 3) for both lentic (b = 2.34) and lotic (b = 1.37) populations. The findings were similar to the records of Shafi and Yousuf (2012), i.e., the population of *P. conchonius* collected from Dal Lake of Kashmir also showed negative allometric growth (b = 2.93 to 2.97) (Table 1). The present findings were also supported by the work of Bahuguna et al. (2021) related to *P. ticto*. The variation of the "b" value was observed to be within the predicted extent of 2–4 as per researchers like Froese (2006) for fishes. For the populations of the species collected from different habitats, body length (Total Length) showed a significant positive correlation with bodyweight. For *P. sophore*, Deshmukh (2023) reported a growth exponent (b = 2.8085) and a condition factor above 1 in Ujani Wetland, suggesting negative allometric growth but healthy environmental conditions. Research from Assam wetlands also recorded

positive allometry, with *P. sophore* (b = 3.30), *P. chola* (b = 3.22), and *P. ticto* (b = 3.27) (Kaushik and Bordoloi 2015). For *Pethia ticto* in the Gomti River, Maurya et al. (2018) observed nearly isometric growth (b ≈ 3.0) with high condition factor values (1.041–1.660), showing good population health. These findings agree with the present study, highlighting that growth patterns in barbs are strongly influenced by habitat conditions. Comparatively higher value of condition factor (K) was observed for the populations of lentic habitat, which indicated better health conditions in lentic habitat owing to the higher plankton production (Serajuddin et al. 2013)

The correlation coefficient between the length and weight was observed to be highly significant ($p < 0.05$) for the population of all species, except for the lentic population of *P. ticto* (Table 1, Fig. 3). The correlational coefficient between logarithmic value of length and weight was observed to vary within the range of 0.98 (*P. chola*) to 0.38 (*P. conchonius*). R^2 value was observed to be high ($R^2 > 0.5$) with the maximum being observed in *P. chola* (0.97) and minimum in *P. conchonius* (0.14). The high value of coefficient of determination, showing high fitness of the regression model to the observed data for both the population of barb species except for lentic population of *P. ticto* and *P. conchonius*. The Fulton's condition factor (K) showed good health condition of the populations of barbs. The descriptive statistics recoded during the present study (Table 1), were considered to be the mean annual values as samples were collected throughout the year and thus not representation of month (Jisr et al. 2018). As illustrated by the present study, change from negative allometry in lotic water bodies to positive allometry in lentic ecosystems for most of the species, has also been confirmed by the relatively high relative condition factor (K). Indeed, the fact that there is higher K indicates that the presence of numerous primary producers leads to better health for fish populations (Calazans et al. 2021).

Relative Condition Factor (Kn) for both lentic and lotic population

The term "Relative Condition Factor" was coined by Le Cren (1951), which actually showed deviation of observed weight from calculated weight, which might be attributed to food, feeding, sexual maturity etc.

During the present study, relative condition factor was computed for both the lentic and lotic populations of the species (Table 2, Fig. 5). The mean deviation value was observed to be more for the lentic populations of *P. sophore* (0.024), and *P. conchonius* (0.057). However, *P. amphibius* (0.012), *P. chola* (0.002) *P. dorsalis* (0.005), and *P. ticto* (0.003) showed comparatively more deviation between the observed and calculated weight for lotic water bodies. Though in most of the species for both the populations, showed more observed weight than calculated weight, but the lentic populationof *P. ticto* showed negative Kn value (-0.139), showing less observed weight than the calculated weight. The present study was supported by the recordings of Singh et al. (2023), i.e. in *Puntius sophore* from Punpun rivers, suggesting habitat-specific differences in fish condition. Meanwhile, *Pethia ticto* populations in the Aasan River exhibited strong seasonal variation in Kn, with lowest values during the monsoon and highest in winter, reflecting seasonal effects on body condition (Bahuguna et al. 2021).

For most of the barb species, lentic water bodies show a much higher "Weight Gain" (OW) across the *Puntius* genus reaching their peak physiological condition in these stagnant, nutrient-rich zones as, the

Observed Weight frequently exceeds the Calculated Weight (positive mean deviation). This suggests that the phytoplankton-rich environment allows the fish to become "stouter" or "heavier". However, in case of *Puntius chola* an exception was observed which might be due to special habitat preference, which was similar with observations by Hossain et al. (2012), suggesting a specialized adaptation to lotic hydrological regimes.

Geometric Morphometry for both lentic and lotic population

Across all six species, PCA and DFA revealed variable degrees of morphological differentiation between lentic and lotic populations, with the magnitude of variation differing by species. In *P. sophore*, the first two PCs explained 43.07% of the total variation (PC1: 22.17%, PC2: 20.90%), while in *P. ticto* the explained variance was higher (PC1: 54.37%, PC2: 11.19%), both clearly separating lentic populations with deeper bodies and longer caudal peduncles from lotic populations with shallower bodies and shorter peduncles, as supported by wireframe diagrams and DFA. In *P. amphibius*, variation was recorded to be 58.40% (PC1: 35.30%, PC2: 23.09%), where lotic populations displayed slightly deeper bodies, while lentic forms differed mainly in caudal fork length. *P. dorsalis* showed negligible differentiation, with populations evenly distributed along PC1 and PC2, and DFA confirming the absence of habitat-related variation. *P. chola* displayed modest variation, with lentic populations evenly spread across both axes and lotic forms clustering on the positive side of PC1, indicative of reduced body depth. In *P. conchonius*, PCA revealed lentic populations concentrated on the negative side of PC1, corresponding to broader body depth compared to lotic ones, with DFA producing consistent results. Collectively, species such as *P. sophore*, *P. ticto*, and *P. conchonius* demonstrated strong habitat-associated morphological divergence, whereas *P. amphibius*, *P. dorsalis*, and *P. chola* exhibited minimal or subtle variation, highlighting interspecific differences in shape plasticity across habitat types (Fig. 6). It is a technique to quantify morphological adaptations of fish to habitats (Gupta *et al.*, 2017). The study revealed that fish populations in the lentic habitat showed broader body depth than those in the lotic habitat, which might be attributed to the more stable hydrodynamic environment of the lentic habitat (Fig. 7). The outcome was recorded to be similar with the findings of Sudasinghe *et al* (2021), who observed that PCA of five Sri Lankan *Pethia* species showed differences particularly with *P. melanomaculata*, with significantly lesser body depth compared to its congeners (*P. bandula*, *P. reval*, *P. nigrofasciata*, *P. cumingii*). This indicates substantial intraspecific morphological variability, likely linked to ecological or evolutionary divergence.

A stable and less disturbed lentic habitat allows fish to adapt to deeper body depths for increased manoeuvrability (Howe et al. 2021), indicating a stouter and heavier body as was observed in case of the length- weight relationship also. On the other hand, the compressed structure of the fish population of the lotic water bodies showed a sleeker streamlined body as an adaptation to the constant fast-flowing currents of streams to reduce the drag (Howe et al. 2021).

Conclusion

The significantly higher observed weight and positive mean values of Relative Condition Factor clearly highlight the direct conversion of the energy gain resulting from the high nutrient content of the standing water into improved biological fitness. The morphological advantage due to better nutrition availability is also evident in the geometric morphometry results, where there was an observable change towards deep-body phenotypes in lentic species – an anatomical adaptation enabled by the absence of current-based selection pressures. On the other hand, the streamlined body shapes and negative allometry in lotic species point to energy costs incurred from increased swimming activity in the habitat. Although deviations from the general pattern in *P. chola* and *P. ticto* hint at niche specialization among the different species, it is undeniable that habitat-related food sources and ecological stability drive the substantial intraspecific variations and good physical condition of these native fishes.

The analysis of length–weight dynamics, morphometric traits, and colour polymorphism in barbs from the Eastern Ghats offers valuable evidence of how freshwater fishes adjust to environmental variability. Deviations from expected isometric growth reflect alterations in hydrological regimes and can therefore serve as reliable bioindicators of habitat quality. Given the ecological and economic relevance of barbs, such information forms a scientific basis for informed fisheries management, conservation planning, and ecosystem restoration in inland waters.

From a biodiversity management perspective, documenting phenotypic plasticity and population-level divergence is crucial, particularly in groups with unresolved taxonomy. These findings provide baseline knowledge necessary for safeguarding native ichthyofauna amid growing anthropogenic stressors. Furthermore, under changing climatic regimes characterized by hydrological instability and resource shifts, the study contributes to understanding species resilience. Incorporating growth and morphometric indices into biodiversity monitoring frameworks can enhance adaptive management, strengthen food and livelihood security, and support long-term climate resilience of freshwater ecosystems.

Declarations

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Further, authors would also like to mention that, as our institution does not have a formal Ethical Care Committee, the protocol for this study was reviewed and approved by the Departmental Research Committee and Board of Studies and was conducted in accordance with national and international guidelines.

Data Availability Statement

The data presented in the manuscript is original and it has no additional data.

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Tables

Tables 1 and 2 are available in the Supplementary Files section.

Figures

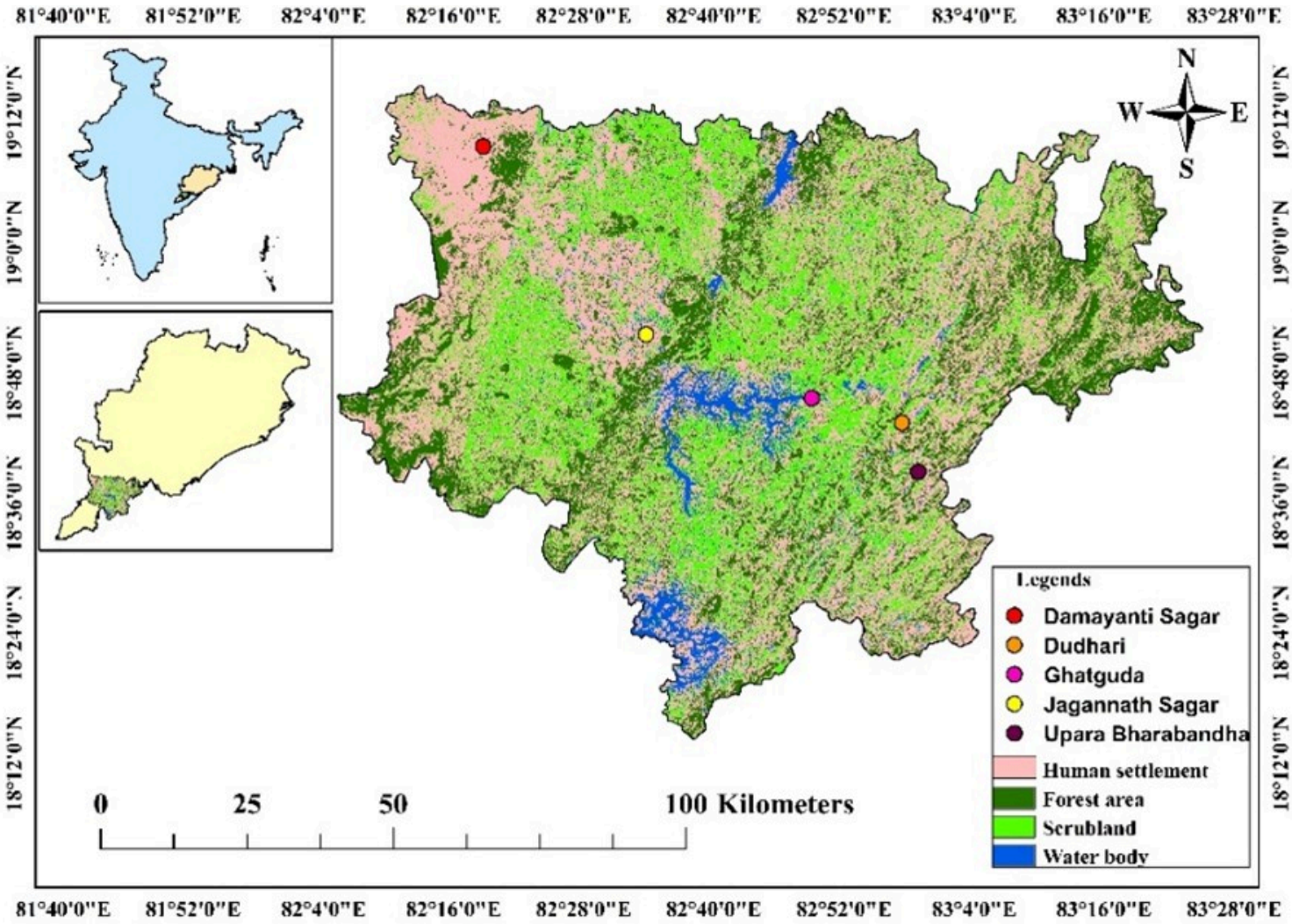


Figure 1

Location of study sites in Koraput District of Odisha

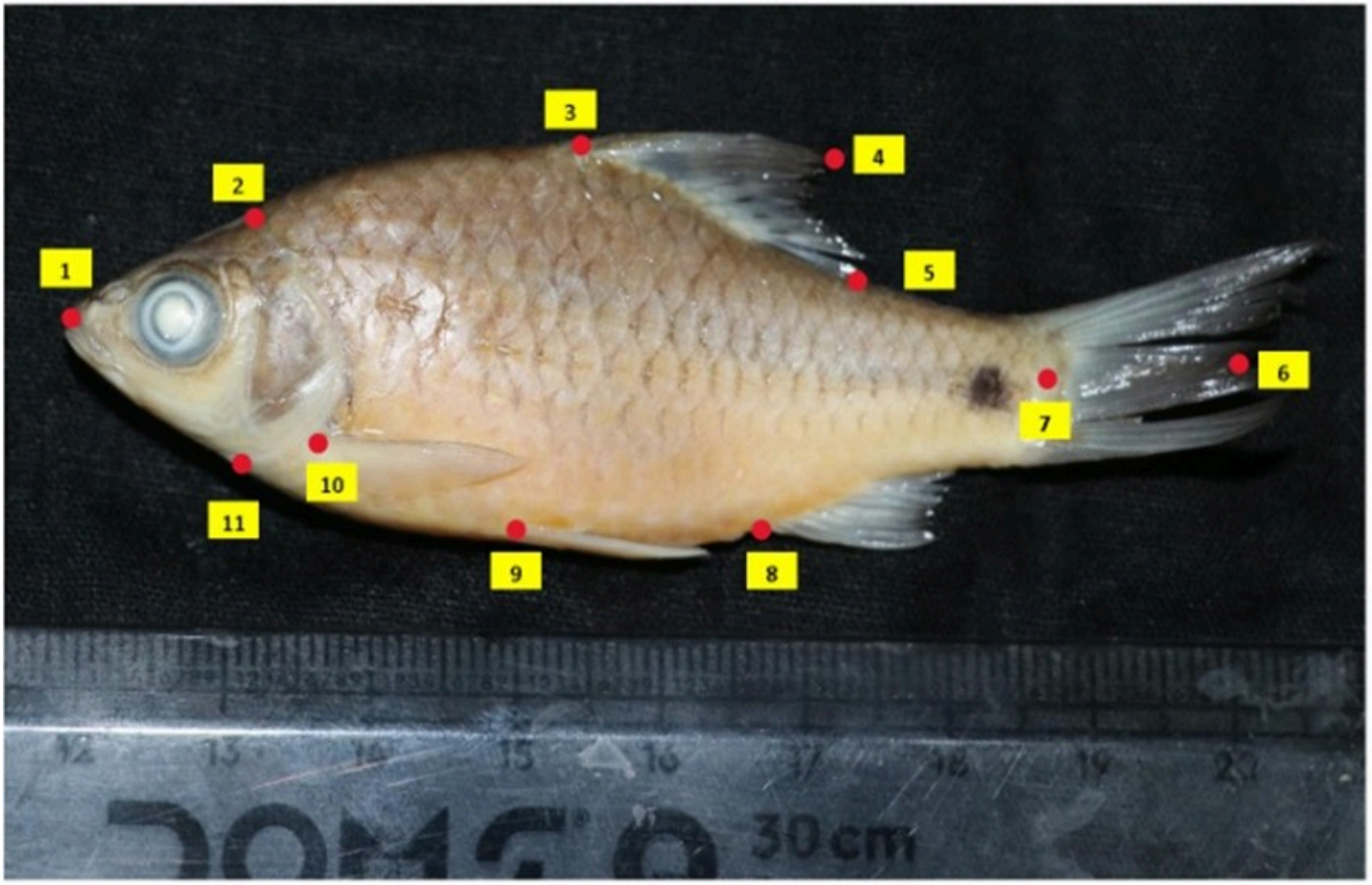


Figure 2

Geometric landmarks for barbs (1) Mouth tip at Upper Lip, (2) Junction between posterior cranial and anterior dorsal region, (3) Anterior origin of Dorsal Fin, (4) End of Dorsal Fin spine, (5) End point of Dorsal Fin Ray, (6) Posterior end of Lateral Line, (7) End of caudal fork length, (8) Anterior origin of Anal Fin, (9) Anterior origin of Pelvic Fin, (10) Anterior origin of Pectoral Fin, (11) Junction between ventral anterior and lower operculum

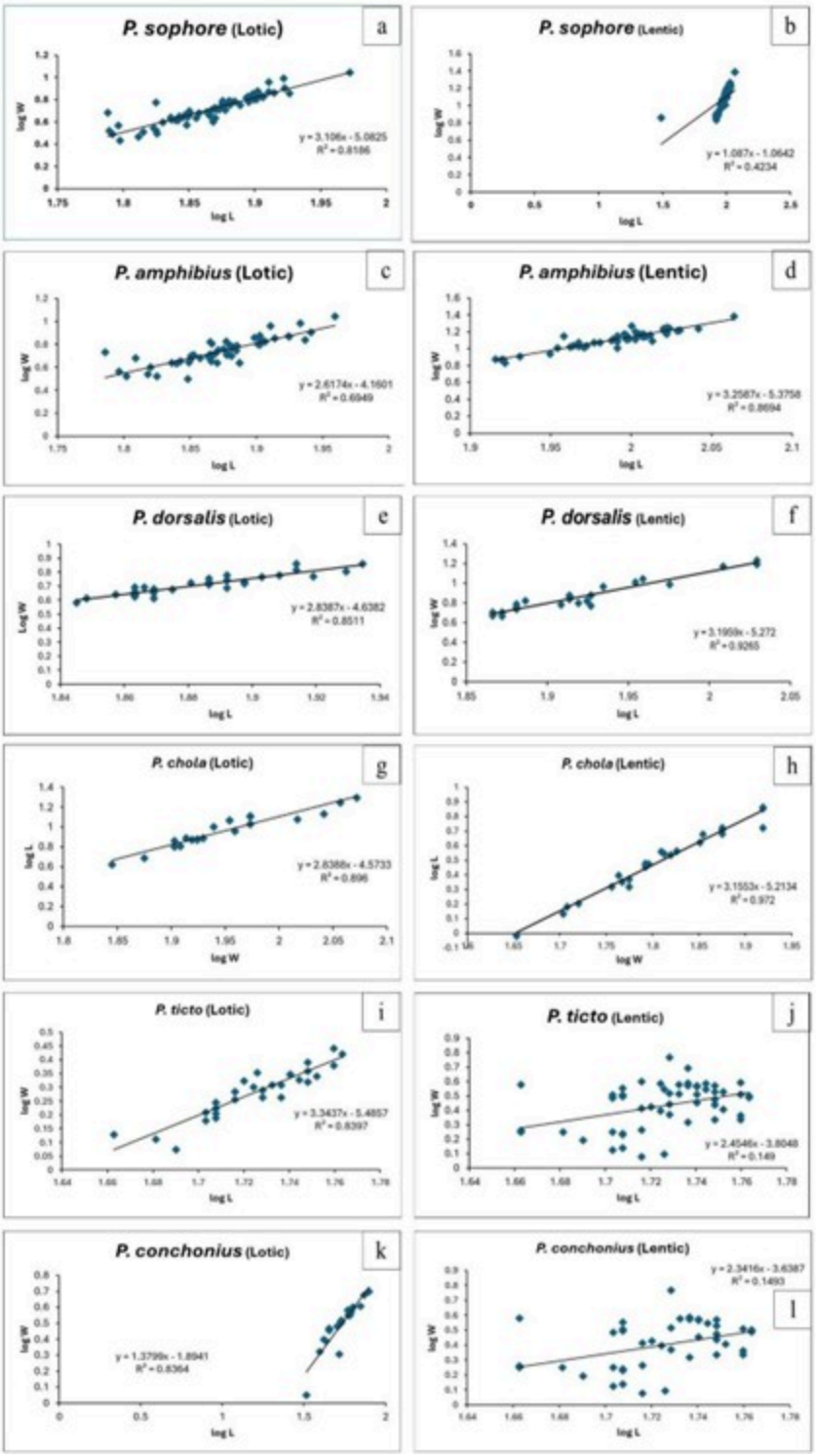


Figure 3

Length-weight relationship of barb species sampled from the two different habitat types (Lotic and Lentic). *P. sophore* (a-lotic, b-lentic); *P. amphibious* (c- lotic, d-lentic); *P. dorsalis*(e-lotic, f-lentic); *P. chola* (g-lotic, h-lentic); *P. ticto* (I- lotic, j-lentic); *P. conchonious* (k-lotic, l-lentic)

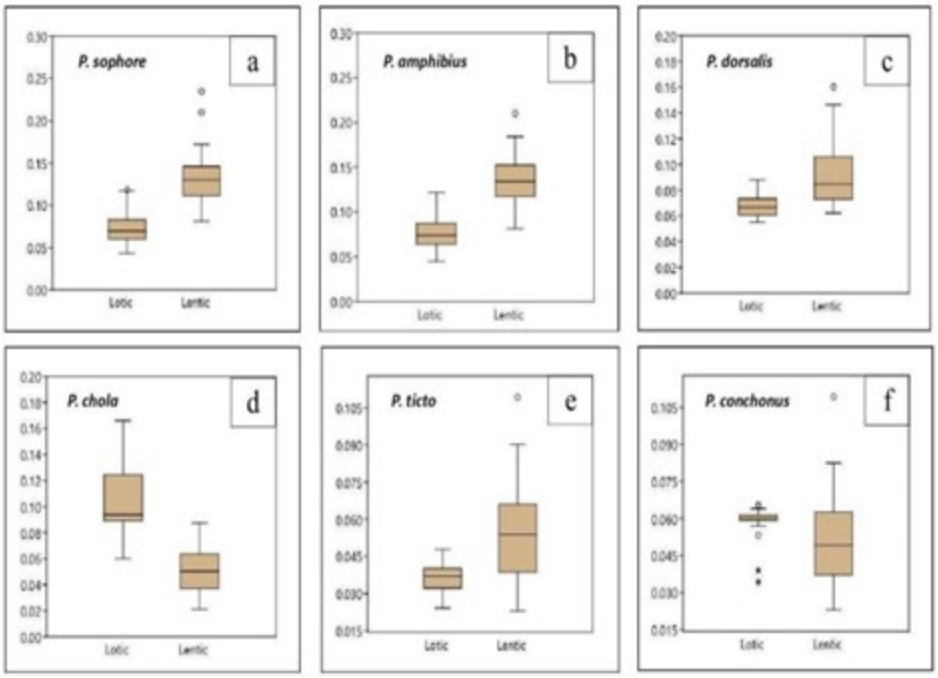


Figure 4

Variation in length in weight for different species collected from the different habitat types. a- *P. sophore*, b- *P. amphibius*, c-*P. dorsalis*, d- *P. chola*, e- *P. ticto* and f- *P. conchonius*

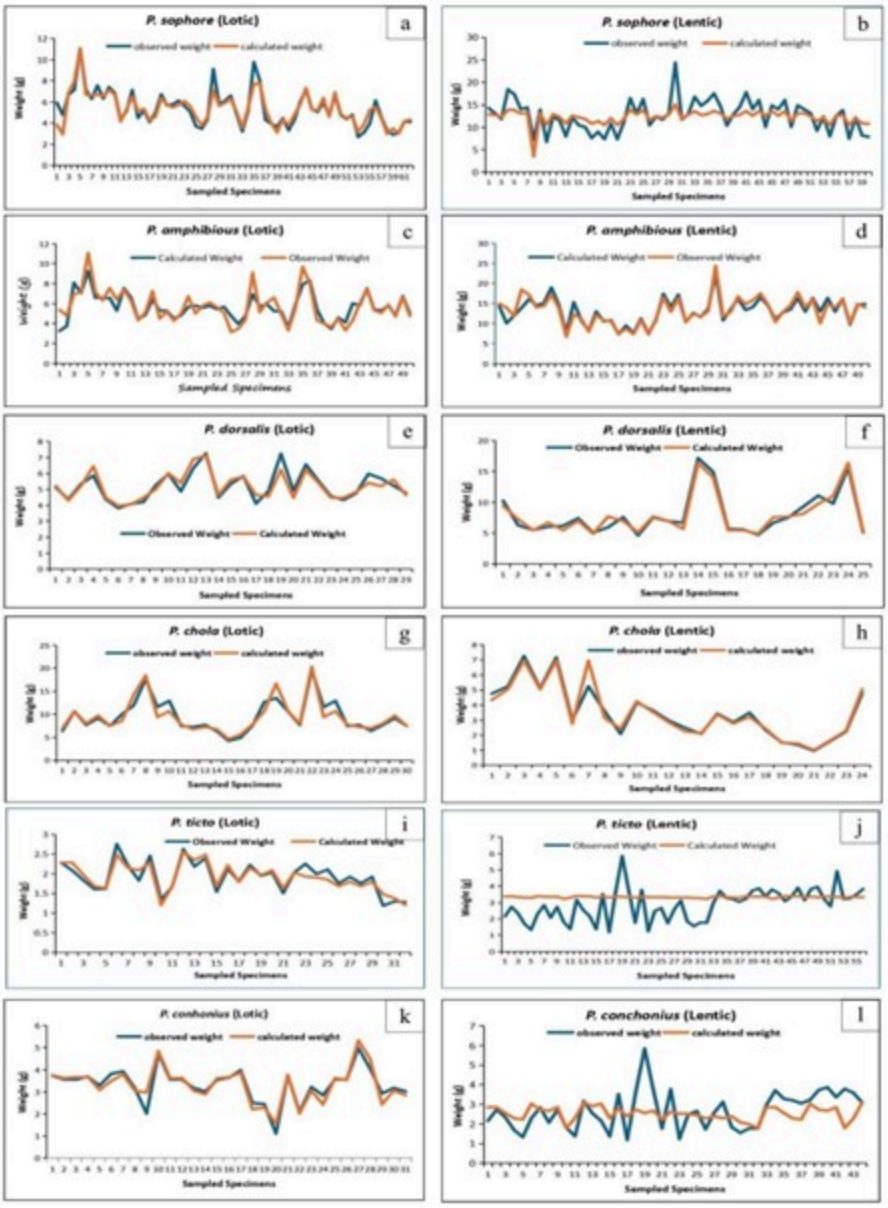


Figure 5

Deviation of calculated weight and observed weight for the collected samples for species collected from different habitats. *P. sophore* (a-lotic, b-lentic), *P. amphibious* (c-lotic, d-lentic), *P. dorsalis* (e-lotic, f-lentic), *P. chola* (g-lotic, h- lentic), *P. ticto* (i-lotic, j-lentic), *P. conchonious* (k-lotic, l-lentic)

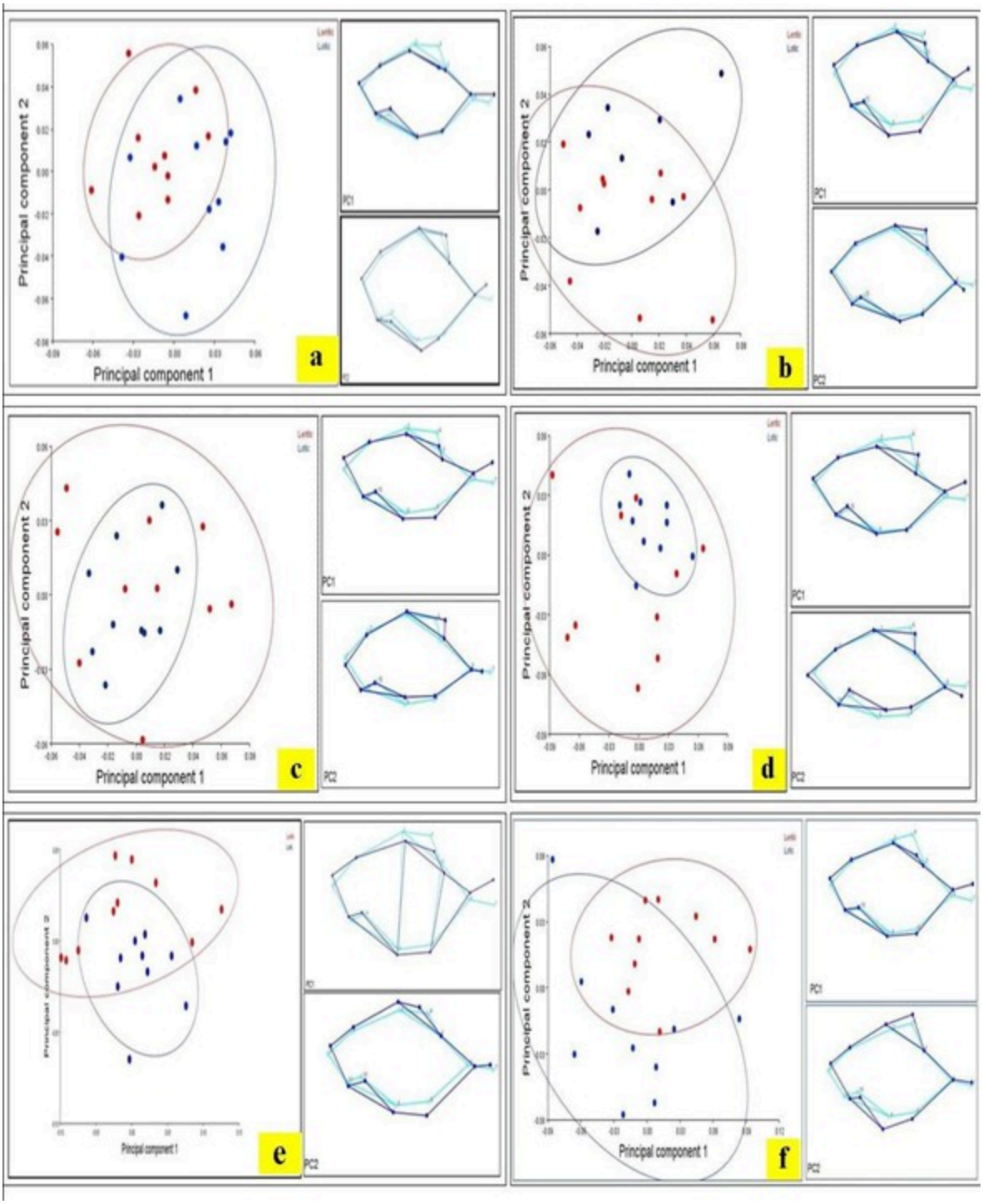


Figure 6

PCA plot (on the left) and corresponding shape variation in the form of wireframe graph (tosca colour representing the mean shape and blue colour showing variation): a- P. sophore, b- P. amphibius, c- P. dorsalis, d- P. chola, e- *P. ticto*, f- *P. conchonius*

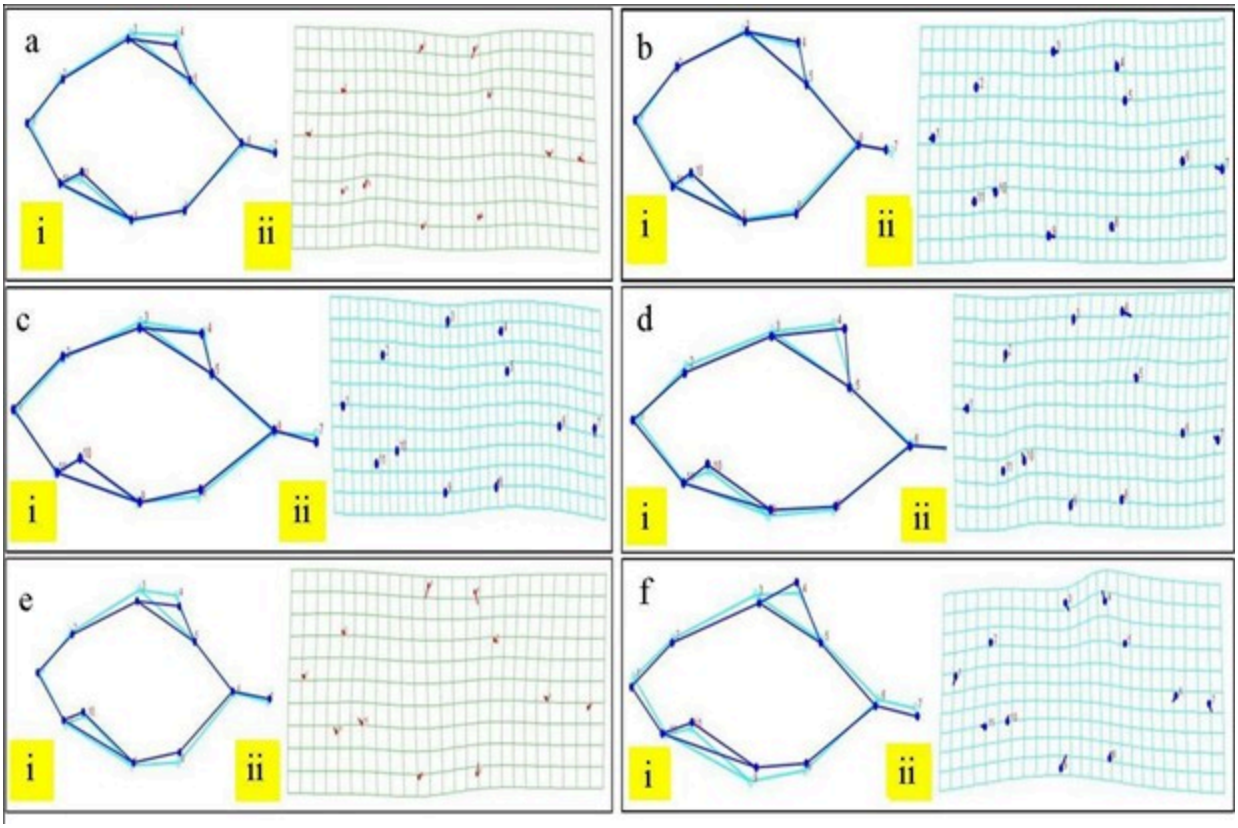


Figure 7

Comparative shape variation between the populations of species (a- *P. sophore*, b- *P. amphibius*, c- *P. dorsalis*, d- *P. chola*, e- *P. ticto*, f- *P. conchonius*) collected from different habitat, illustrated in – a) wireframe graph, where the line in tosca colour represents the lentic habitat and blue colour represents the lotic habitat; b) transformation grid, lentic type represented by the lolly and tip (rod) part represents the lotic type. The length and the projection of rods indicate the variation of shape for the two populations

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table1.docx
- Table2.docx