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Body Shape Variation Between Two Populations of the White Goby, *Glossogobius giuris* (Hamilton and Buchanan)

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Abstract: The major objective of this study is to determine the body shape variation among and between the two populations (Lake Lanao and Lake Buluan) of *Glosssogobius giuris* (Hamilton and Buchanan), using landmark-based geometric morphometrics. A total of 33 specimens from Lake Lanao (17 males, 16 females) and 31 from Lake Buluan (16 females, 15 males) were examined. Nineteen landmark points were digitized on the specimens from which relative warp scores were derived. Discriminant function analysis showed that both populations exhibit sexual dimorphism. Body shape between the two populations also shows significant difference, with Lake Lanao gobies having bigger head aspect ratio (low) and mouth with a narrower body and more elongated dorsal and anal fins. These characteristics are suggestive of a more efficient carnivore with a more active habit or a fast flowing environment for Lake Lanao gobies.

Key words: landmark-based geometric morphometrics, Procrustees distance, relative warp analysis

INTRODUCTION

Exposed to different environmental conditions, fishes, like all organisms are capable of making adaptations to enable them to survive. In fact the environment is recognized as a powerful force in modelling the morphology of an organism during ontogeny[4]. Webb[26] showed evidence that body shape is a reliable indicator of the swimming behaviour and habitat choice of fishes. Body shape therefore is not only a reflection of genetic character, but also its environment and its habit[11]. Barlow (1961), noted that a swimming fish and a fish that live in fast flowing waters tend to have fusiform shaped bodies, while Hubbs,[20] observed that a fish living in static waters often have more compressed and deeper bodies as a reflection of their environment.

Lakes are confined bodies of water and any freshwater fish populations living in such lakes are usually confined to the limits of that environment and are isolated from other freshwater fish populations of the same species. As such, these populations living in different lakes may be exposed to contrasting environmental conditions and may exhibit locally adaptive morphological variations making them different from other populations of the same species.

The Philippines, has several large lakes. Two such lakes are Lake Buluan and Lake Lanao all located in Mindanao, which is inhabited by a number of freshwater fishes, among them the White Goby, *Glossogobius giuris* (Hamilton and Buchanan).

The White Goby is a freshwater fish that lives in freshwater but spawns in seawater. It is widely distributed in the rivers and lakes throughout the Philippines and like all gobies they are bottom dwellers where their fused pelvic fins provide them with a suction disk for clinging to bottom substrate. The adults are considered of minor commercial value because of its small size, but in many parts of the Philippines its fries contribute to the so called “ipon” fishery during its breeding months[12]. The adults may attain a length of about 350 mm. This species is native to Lake Buluan, where it was first recorded by Herre in 1927, and in lake Lanao, where it was accidentally introduced in the 1960s[22]. No attempt has been made to determine body shape differences among the populations of this species in the Philippines.

The major objective of this study is to compare the body shape variation within and between the two populations of *G. giuris*, from two lakes in Mindanao, using landmark-based geometric morphometrics.

METHODOLOGY

Description of the Areas Where Specimens were Collected: Lake Buluan (6°39'N, 124°50'E) along with its associated marshes, is the third largest lake (6,500 has) in Mindanao (Fig. 1). The lake is fed by a river

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rising in the hills of southern Mindanao, and drains via the Buluan River into the Mindanao River. It has an altitude of 35 m, with a depth of 3-6m. On the other hand, Lake Lanao (8^0 00' N, 123^0 50' E) is the largest (357 km^2) lake in Mindanao with a mean depth of 60.3 m and an altitude of 702 m. Five major river systems drain into the lake from the surrounding watershed areas, while Agus River is the one and only river draining the Lake on its north side. This river flows for about 35 km down to the coastal area of Iligan City, where the 57-m vertical drop of Maria Cristina Falls, isolate the entire lake Lanao plateau from the influence of the marine biota of the sea.

Landmark-based geometric morphometrics was used to analyze body shape variation of the specimens, using the series of TPS softwares written by F. James Rohlf of SUNY, Stony Brook, which is available at SB Morph worldwide websites. Morphometrics is the study of shape variation and its co-variation with other variables[1].

Traditionally, morphometrics was the application of multivariate statistical analyses to sets of quantitative variables such as length, width, and height. However, the effectiveness and adequacy of these characters to describe body shape depend much on the choice of measurements used. Rohlf [21] presented a new approach in the field of morphometrics that take into account measurements to capture various changes in body form. It is called "geometric morphometrics". One major advantage of this approach is that the result of the analyses could be visualized as configurations of landmarks back in the original space of the organism rather than only as statistical scatter plots.[1] Briefly, the method involve: (1) capturing the images of specimens (2) quantification of shape data by digitization of landmarks on the images (3) superimposition of the landmarks using General Procrustees Analysis (GPA) to remove non-shape variations and produce the shape variables of partial warp scores (4) visualization of shape variation (5) multivariate analysis of shape variables.

Subsequent multivariate analysis of the partial scores were computed using PAST (PAleontological STatistics) by Hammer et al., (2001) version 11.91. To reduce the complications of body shape variation due to allometric growth patterns, only adult specimens ranging in size from 240 mm to 300 mm were used.

Processing and Digitization of the Specimens: Digital images from the left side of Lake Buluan samples were prepared from fresh specimens bought from local fishermen in the area. These were produced by a flat-bed scanner at a resolution of 600 dpi. From among 60 of the images, 31 (16 females and 15 males) were chosen for their excellent quality and included in this study. Sexing by examination of the gonads was done after scanning.

Specimen samples from Lake Lanao were bought from local fishermen in Marawi City market and scanned while still fresh. Following the same procedure as above, 33 (16 females and 17 males) digital images were chosen from 60 digital images.
Nineteen landmarks were digitized on the images using the TpsDig (version 2.12) as shown in Fig. 2.

Figure 2. A scanned image of *Glossogobius giuris*, digitized with the 19 landmarks as follows: (1) snout tip; (2) and (3) anterior and posterior insertion of the first and second dorsal fin; (4) and (6) dorsal and ventral region of the caudal peduncle where there is the greatest curvature; (5) posteriormost body extremity; (7) and (8) posterior and anterior insertion of the anal fin; (9) insertion of the pelvic fin; (10) insertion of the operculum on the lateral profile; (11) posterior extremity of premaxillar; (12) centre of the eye; (13) superior insertion of operculum; (14) point of maximum extension of operculum on the lateral profile; (15 and 16) superior and inferior insertion of the pectoral fin; (17) and (18) superior and inferior margin of the eye; (19) superior margin of the pre-operculum.

Analysis of Partial Warp Scores: The resulting partial scores of the images, were then subjected to relative warp analysis using the TpsRelw (version 1.45), which quantifies body shape of the specimens. It also plots the landmarks in a two dimenstional morpho-space warp grid where variations are shown as deformations of the grids. Images from the two populations were separated into male and female to produce the consensus configuration of each sex for comparison of body shape between the sexes. To determine the shape variability of each population the images of the two sexes were pooled in one analysis.

To determine if shape varied significantly among and between the two populations, pooled partial warp scores of the sexes from both populations were subjected to Discriminant Function Analysis (DFA). In DFA the partial warp scores were treated as independent variables and a multivariate function was defined such that males and females were maximally discriminated.

To visualize the differences between compared shapes, the software tpsSpline, (version 1.20) was used. It produces transformation grids that show the shape change from a grid with square cells superimposed onto the average landmark configuration to a grid that is deformed to fit a target configuration. This comparison is based on Procrustees distance (d^2), which is the standard measure for the magnitude of shape differences used in geometric morphometrics (e.g. Bookstein, 1996). Procrustes distance is an absolute measure of the degree of shape difference between two configurations, and therefore does not depend on factors like the variation within samples. Differences in shape represented in this fashion are a mathematically rigorous realization of D'Arcy Thompson's (1917), idea [1]where one object is deformed or warped into another.

RESULTS and DISCUSSION

Sexual Dimorphism With-in the Two Populations. Body shape variation in a population can be explained by sexual dimorphism. As shown in Fig. 5, both populations exhibit sexual dimorphism (both $p<0.05$).

The figure also shows a clearer distinction of shape between sexes of Lake Lanao gobies, though the shape difference is greater in Lake Buluan gobies ($d^2 = 0.02250$) compared to Lanao gobies ($d^2 = 0.01839$) (see Fig. 3).

This body shape difference between sexes for both populations follow the same pattern, as shown in Fig. 4, with the males for both populations having a bigger and deeper head and a bigger gape, a shallower body and a elongated anal fin compared to females.

Caudal peduncle of males is also deeper with the anal fin being more elongated. These variations would produce a more tubular shape, with a minimal shoulder area from a shallower body and tapering gently towards a deeper caudal peduncle, that would minimize drag and create a more streamlined body shape for males.

This observed sexual dimorphism is in concordance with the study of Ostrand *et al*., [5]on Plains Minow, *Hybognathus placitus*, with the males showing larger heads and caudal peduncle while females are deeper bodied. Spoljaric and Reimchen,[24] also showed males from populations of Threespine Stickleback (*Gasterosteus aculeatus*) are characterized by larger heads, larger gape, posteriad dorsal spines, posteriad pelvis, longer anal fin, and deep posterior caudal depth relative to those in females.

Several other studies showed the same trend in sexual dimorphism, particularly, as cited by Spoljaric et al.,[24], the studies of Kristjánsson *et al.*, 2002; Reimchen & Nosil, 2006; and Kitano *et al.*, 2007. It would seem then, that the observed pattern of sexual dimorphism is not unique to *G. giuris*, but may be common among fishes exhibiting sexual dimorphism.

Sexual selection has often been pointed to explain sexual dimorphism[19], as oftentimes these characters would signify superior traits which would be preferred by the opposite sex. These characters become very prominent especially during the spawning season, as in case of Salmon (Wilson, 1997). Such dimorphism, at least in some fishes, are transient. Spoljaric and Reimchen,[24], however, suggests that sexual dimorphism may be a functional adaptation for different habits of the the two sexes with the deeper body of one sex suggesting an adaptation for rapid acceleration and maneuverability whereas, the more fusiform bodies of the other sex lowers drag during steady swimming in open waters. Burns *et al*.,[2] made the same suggestion when his wild-caught females of *Poecilia reticulata*, showed smaller heads and deeper caudal peduncles than wild-caught males compared with laboratory-reared specimens which showed no such difference.

The above mentioned studies all pointed to habitat difference or habit to explain sexual dimorphism. In this study, the lack of observed indications of spawning among the specimens (enlarged ovaries filled with maturing eggs) would seem to rule out sexual selection to explain the observed sexual dimorphism. Thus, the observed sexual dimorphism may only be explained as a difference in habit or habitat between the sexes with the slimmer and more tubular body shape of the males suggesting either a more active habit or a preference for a habitat of strong water flows.

Body Shape Difference Between the two Populations. Comparison of body shapes between males and between females from both populations shows highly significant differences (Fig. 5).

These differences are shown by their consensus configurations and the Thin Plate Spline plot of both sexes against each other (Fig. 6). The Lake Lanao population shows a bigger and head, bigger gape, shallower body, deeper caudal peduncle, and an elongated anal and dorsal fin compared to Lake Buluan gobies.

Phenotypic variation among organisms in nature may be viewed as important only if any differences in morphology translate into an increased in fitness among the different groups. In an aquatic medium it means subscribing to the demands of hydrodynamic forces to conserve energy while maintaining its preferred behavior.

Fishes living in an environment of strong water flows or with a habit of swimming continously, will have to conform to this environment and habit. The observed slimmer and more tubular body shape of Lake Lanao gobies would then suggest a more active habit or a habitat of strong water current. According to Pulcini *et al*.[4]an elongated body shape with a minimal shoulder area and tail area reduces reduces drag, thus fishes in this type of habitat develop a more efficient streamlined body shape [24,2].

According to Walker[25], body undulations are used by most fishes for steady swimming at typical cruising speeds, while manoeuvres are commonly controlled by fin motions with or without axial bending. The dorsal and anal fin in general, function in stabilizing the body during displacement, but may also help generate propulsion especially when these fins intercept with the caudal fin[16].

Thus, according to Pulcini *et al*.[4], shorter and more backward located dorsal fins are typical of sprinters, while an elongated and more anteriorly located dorsal fin functions more in stabilizing side to side motions during displacement. The anal fin performs the same function by virtue of their posterior median position. The observed elongated dorsal and anal fins of Lake Lanao gobies would suggest a lot of movement that requires the stabilizing effect of such fins, thus giving them greater manoeuvrability.

G. giuris is described by Herre[15] as "carnivorous bottom dwellers". This carnivorous habit is well evidenced by its large head with a large mouth[23,15] and strong sharp teeth. In fact, Islam[16] and Marquez [18] reported that crustaceans formed the major food of the juveniles while adults of this species prefer fish. The carnivorous habit of fishes is usually constrained by the size of their mouth [23] as it would limit the size of their prey. A bigger mouth would give them a wider choice of prey and along with a bigger head, the necessary mechanical parts to tackle such bigger-sized prey. The bigger mouth and head observed among Lake Lanao gobies would then offer them and advantage.

Summary and Conclusion: The variability observed among the two populations is in terms of body depth, size of head and mouth and length of the fins. Sexual dimorphism explains much of this variability and can be explained as difference of habit or of preferred habitat between opposite sexes with the slimmer body of the males being adapted to a more active habit or a habitat with fast water flows. A difference in morphology between the two populations is evident with Lake Lanao gobies exhibiting slimmer bodies enlarged head and mouth, and elongated dorsal and anal fins. These differences would are suggestive of a more active and more efficient carnivorous habit.

According to Turan [6], differences in morphology due to environmental adaptations need not be reflected into genetic changes of a population but may involve modifications in their morphology that would result into changes in their physiology and behaviour. Such changes may effectively bar them from interacting with the original population resulting into the formation of sub-populations. Booke (1981) defined stock as "a group of individuals within a species which maintains a set of characteristics which are environmentally dependent". The result of the present study could be taken as one evidence to consider the two populations as separate stocks.

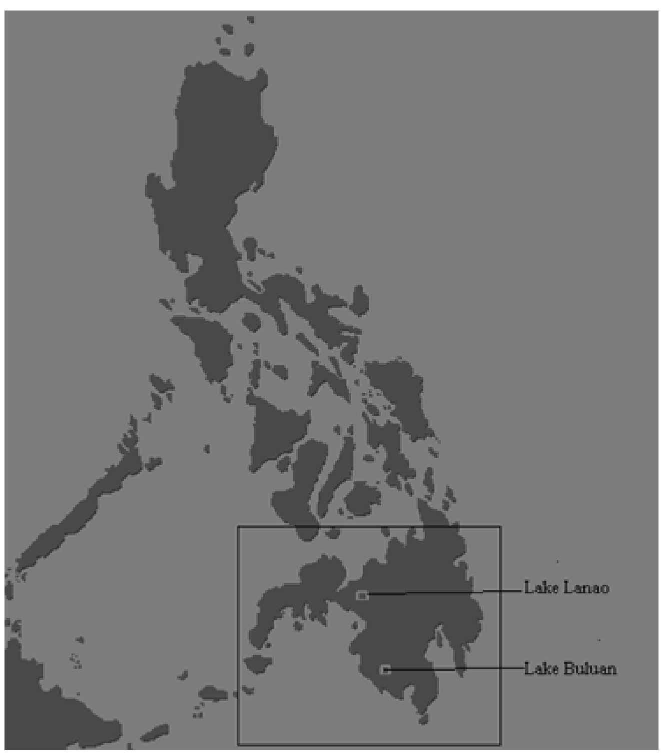

Fig. 1: Map of the Philippines showing the approximate locations of Lakes Lanao and Buluan in the island of Mindanao (boxed).

Fig. 2: A scanned image of Glossogobius giuris, digitized with the 19 landmarks as follows: (1) snout tip; (2) and (3) anterior and posterior insertion of the first and second dorsal fin; (4) and (6) dorsal and ventral region of the caudal peduncle where there is the greatest curvature; (5) posteriormost body extremity; (7) and (8) posterior and anterior insertion of the anal fin; (9) insertion of the pelvic fin; (10) insertion of the operculum on the lateral profile; (11) posterior extremity of premaxillar; (12) centre of the eye; (13) superior insertion of operculum; (14) point of maximum extension of operculum on the lateral profile; (15 and 16) superior and inferior insertion of the pectoral fin; (17) and (18) superior and inferior margin of the eye; (19) superior margin of the pre-operculum.

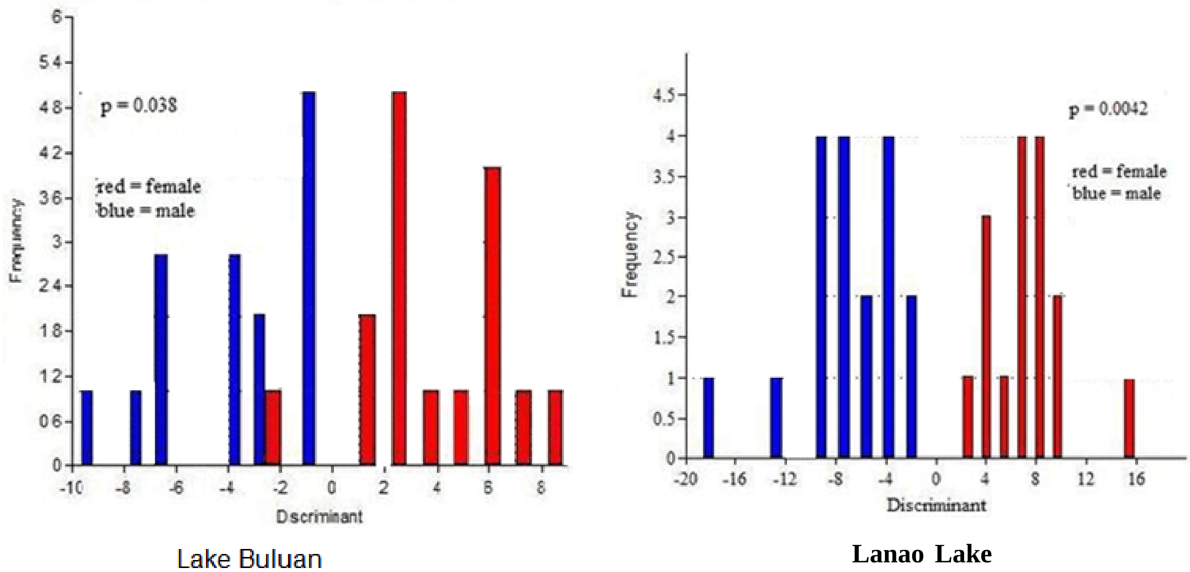

Fig. 3: Graphs of the Discriminant Function Analysis of the relative warp scores of body shapes among gobies from Lake Buluan and from Lake Lanao.The two graphs show significant differences between body shapes of both sexes in both populations. It also show that body shape difference between sexes is more distinct in Lake Lanao Gobies (p = 0.0042) with a clear separation between males and females compared to Lake Buluan Gobies (p = 0.038).

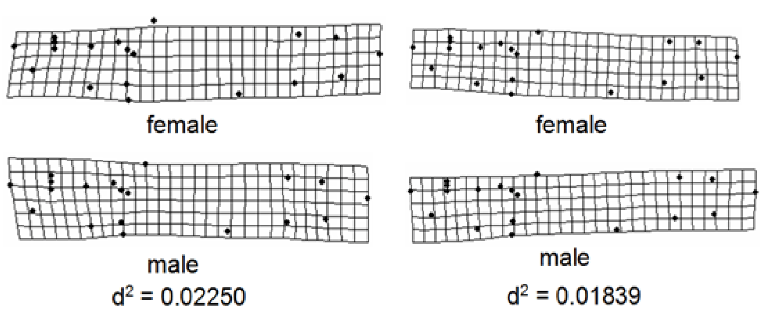

Fig. 4: Thin Plate Spline plot of both populations It shows bigger head, shallower body and longer anal fin for males of both populations. The caudal peduncles of males are deeper for both. Shape difference between sexes is greater for Lake Buluan gobies (d2 = 0.02250) as opposed to Lake Lanao gobies gobies (d2 = 0.01839).

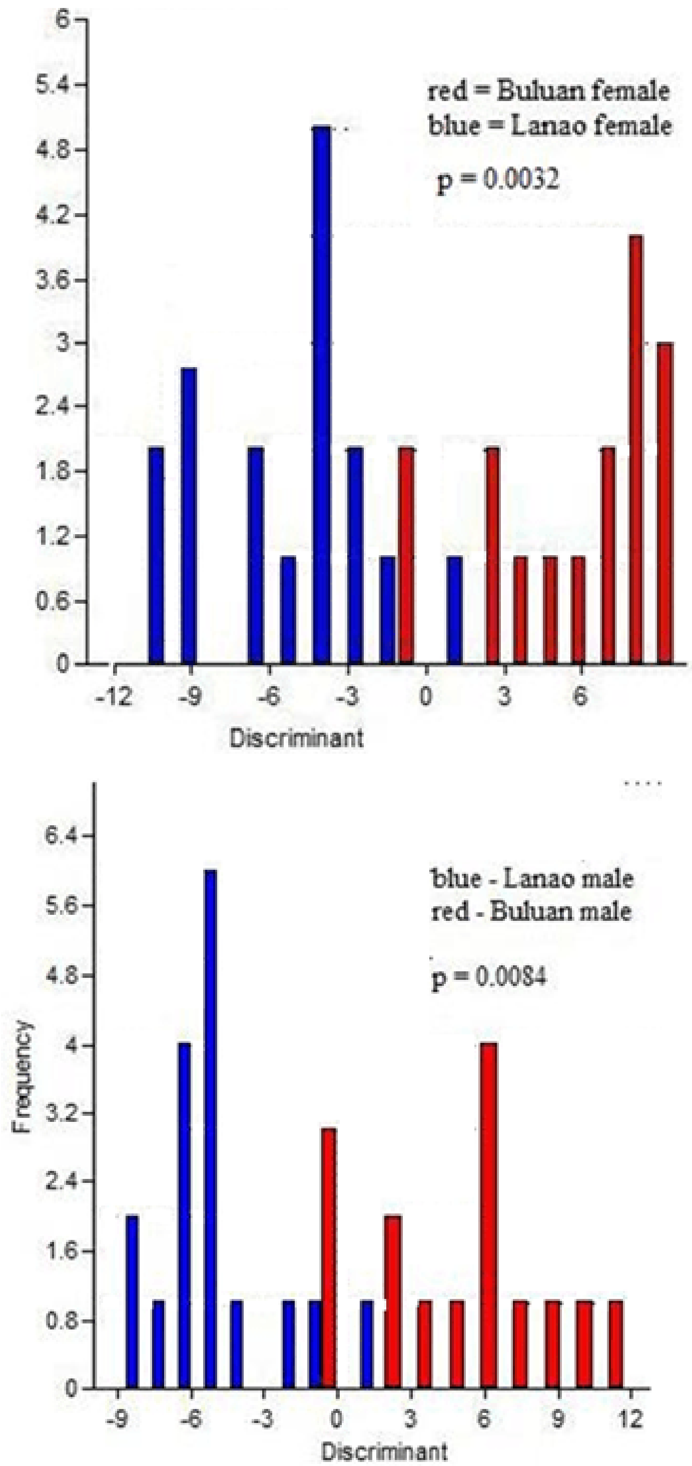

Fig. 5: DFA graph of the frequency and distribution of partial warp scores of body shape variation between sexes of both populations which is both highly significant with p = 0.0032 for females and 0.0084 for males .

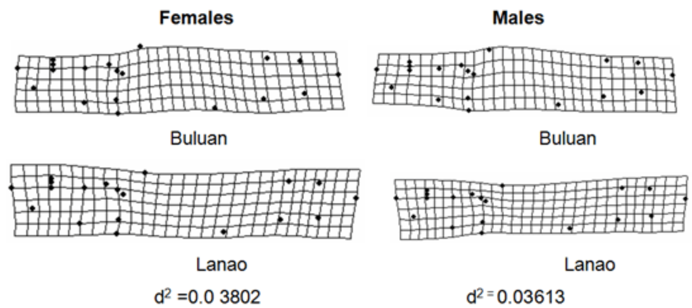

Fig. 6: Thin Plate Spline plot of both sexes between the two populations of gobies The male (right column) and the female plots show the same pattern of a bigger head, a bigger gape, a shallower body and a deeper caudal peduncles for Lake Lanao gobies. The anal and dorsal fins are also elongated for Lake Lanao gobies. Females show a slightly greater shape difference (d2 = 0.0 3802) compared to males (d2 = 0.03613).

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