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Research Article

The Diversity of Ray-finned Fishes (Actinopterygii) in Plio-Pleistocene Java

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ABSTRACT

Java has been known in the world of Paleontology as a contributor to the findings of *Homo erectus* fossils, but there are still other fossil findings that have not been identified until now, especially fossil fishes of the subclass Actinopterygii. This research was conducted to recognize the diversity of the actinopterygians fishes in Plio-Pleistocene of Java and to determine the diagnostic characters of each taxon group of fossils in the Plio-Pleistocene of Java. The study was carried out using comparative anatomical methods with present-day specimens and fossil findings collection of the Laboratory of Bioanthropology and Paleoanthropology, Faculty of Medicine, Public Health and Nursing, Universitas Gadjah Mada; Bandung Geological Museum and Sangiran Early Man Site. The research found at least 8 species of fish fossils in Java which belong to three order, i.e., the order Siluriformes with 5 identified species: *Bagarius gigas, Hemibragus nemurus, Clarias macrocephalus*, family Ariidae with indeterminate genus or species, *Plotosus canius, Clarias batrachus*, and family Pangasiidae with indeterminate genus or species; the order Perciformes with two identified species: *Anabas testudineus* and *Sphyraena crassidens*; and the order Cypriniformes with one identified species: *Osteochilus vittatus*. Based on the fossil findings showed that the Java Island during the Plio-Pleistocene used to be a marine environment that gradually ascending into a lowland river which closes to mangrove swamps and estuaries while the ancient Bandung lake site was a lacustrine environment with calm currents and is overgrown with riparian vegetation.

Keywords: Actinopterygii fish, fossil, Java island, Plio-Pleistocene

INTRODUCTION

The fish fossils in Java belonged to the Trinil HK faunal group, which were 0.9 million years ago. Those fossils were members of the order Perciformes, such as; *Anabas testudineus* (Anabantidae) and *Channa* cf. *striata* (Channidae), members from order Siluriformes such as; *Clarias batrachus*, *Clarias leiacanthus* (Clariidae) and *Hemibagrus nemurus* (Bagridae) (Joordens *et al*., 2009). Those identified fossils belonged to the subclass Actinopterygii. The actinopterygian fishes are characterized by pectoral radials (actinosts) and interopercle bones which can be fossilized (Nelson *et al*., 2016).

The fossil fishes found in Java were inhabited the Bengawan Solo River during the Pleistocene, and far from the sea waters. At that time the terrestrial waters were murky lowland rivers, with several lakes, areas with sunken trees and aquatic vegetation, swamps with low oxygen levels, and estuaries with brackish water. This research was considered to be insufficient as a database in the inventory of fossil fish in Java because there were still many fossil fish specimens that have not been included in the study, therefore this study was conducted to complete the data from previous research.

The purpose of this study was to recognize the diversity of actinopterygians fossil of fish and to determine the diagnostic character of each group of

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fossil taxon in Pleistocene of Java and to understand the condition of the ancient environment where the fish lived.

MATERIALS AND METHODS

Materials

The study was carried out using comparative anatomical methods between present-day specimens with fossil findings collection of the Laboratory of Bioanthropology and Paleoanthropology, Faculty of Medicine, Public Health and Nursing UGM (abbreviated as LBP), Bandung Geological Museum (abbreviated as BGM) and Sangiran Early Man Site (abbreviated as SEMS).

The present-day material studied was preserved hard parts of the Actinopterygii fishes. The preserved hard parts of several recent fish species were specimens' collection of the Laboratory of Animal Systematics, Faculty of Biology UGM (abbreviated as LAS). Those specimens were *Arius nella*, *Clarias batrachus*, *Pangasius* sp, and *Hemibragus nemurus*. We also used a skeletal identification book titled Osteological Guide of Fishes from the Mekong System (Voeun, 2006).

Methods

The data taken were qualitative which obtained by objectively describing and observing the morphology by focusing on the characters that could be used as markers in each part of the skeleton. The character was based on the skeletal part. The anatomical parts were recorded by their general shape, ornamentation, surface, and special features of the specimen (Voeun, 2006).

Each fossil found was compared with the preserved specimens and the fish skeleton identification book by Voeun (2006). Identified species were then compiled into tables and lists of fauna on the island of Java at the time the fossils were discovered. Paleoecological data were secondary data obtained from sedimentary geological data and identified species information.

RESULTS AND DISCUSSION

Fossil Findings

There were a total of one hundred fragments of fossil fishes from three locations (LBP, BGM, and SEMS) have not been identified. The majority of fossil findings were members of the order Siluriformes because Siluriformes fishes possess a sturdy bone structure of pectoral spine and Neurocranium which was easier for the fossilization process. This structure also can be used as distinguishing characters of each species. At least 8 species of actinopterygians fish fossils were found in Java (Table 1), which belong to the order Siluriformes, Perciformes, and Cypriniformes.

Systematic Descriptions

Order Siluriformes G. Cuvier, 1817

Family Clariidae Bonaparte, 1846

Clarias batrachus (Linnaeus, 1758)

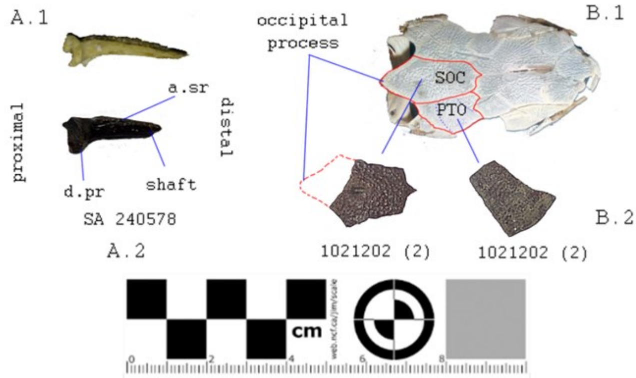

Figure 1. Fossils (A.2) pectoral spine and (B.2) neurocranium fragments of *Clarias batrachus* catfish with recent specimens as a comparison (A.1 & B.1). A.Sr = Anterior serration, D.Pr=Dorsal Process, SOC=Supraoccipital,PTO=Pterotic.

Material examined: A pectoral spine and two fragments of neurocranium (Figure 1) collections of Bandung Geology Museum.

Diagnostic characters: Pectoral spine, the base of the shaft is not too protruding compared to *Plotosus canius*, the anterior part serration is more dominant even though the fossil has been eroded (Figure 3, SA 240578). Characters resemble modern species but are not entirely identical types. The neurocranium is very identical due to the presence of occipital processes which are evident in the posterior part of the supraoccipital plate (Figure 3, 1021202 (2)).

Clarias macrocephalus Gunther, 1864

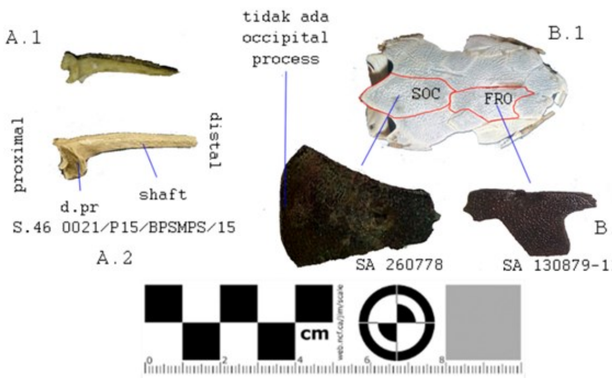

Figure 2. Fossil (A.2) pectoral spine and (B.2) fragments of neurocranium of *Clarias macrocephalus* with a recent specimen of *Clarias batrachus* as a comparison (A.1 & B.1). D.Pr=Dorsal Process, SOC=Supraoccipital, FROO=Frontal.

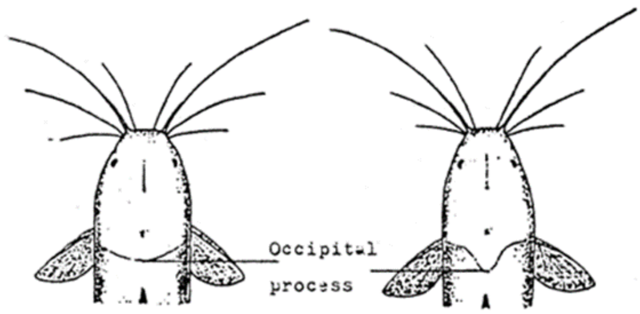

Figure 3. The distinguishing character of *Clarias macrocephalus* (left) and *Clarias batrachus* (right) is the presence of an occipital process on *Clarias batrachus*. (Srisuvantach, *et al.*, 1985).

Material examined: 15 specimens of pectoral spine at Sangiran, 3 specimens of spina pectoralis at the Bandung Geological Musem along with 3 pieces of fragments of neurocranium.
Diagnostic characters: Pectoral spines are relatively thinner and finer in the surface, shafts bend in posterior direction, and dim serration (Figure 2, S.46 0021/P15/BPSMPS/15). Larger in size than modern *Clarias batrachus*. Neurocranium fragments are thin plates with a surface full of granules but they do not have an occipital process that extends posteriorly like *Clarias batrachus* (Figure 2, SA 260778).

ARIIDAE L.S. Berg, 1958
Indeterminate genus and species.

Figure 4. Several pieces of pectoral spine (A.2) fossil specimens from Ariidae's family with the recent specimen (A.1) as a comparison. a.Sr = Anterior serration, p.Sr = Posterior Serration, D.Pr = Dorsal Process.

Material examined: 3 pectoral spine specimens collection of Sangiran Early Man Site, 1 pectoral spine collection of Bandung Geological Museum along with a fragment of neurocranium.
Diagnostic characters: The shaft of pectoral spine is flat and straight, there are serration on both sides of the shaft but is more dominant on the posterior side. Groove is parallel horizontally along the shaft (Figure 4, S31 & S38), serration exists on both sides but the posterior side tends to be more evident (Figure 4, SA 100979).

PLOTOSIDAE Bleeker, 1858
Plotosus cf. *canius* (Hamilton, 1822)

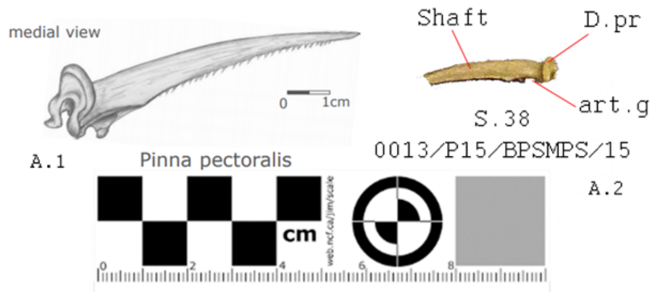

Figure 5. Pectoral spine fossil (A.2) of *Plotosus canius* fish with a comparison from Voeun (2006) (A.1). D.Pr=Dorsal Process. Art.g=Articular groove.

Material examined: A pectoral spine collection of Sangiran Early Man Site.
Diagnostic characters: Small pectoral spine, the proximal shaft protrudes anteriorly, shaft surface is smooth with small serration at the edges (Figure 5. S.38), but in the fossil specimen, the serration is absent or not fossilized.

PANGASIIDAE Bleeker, 1858
Indeterminate genus and species.

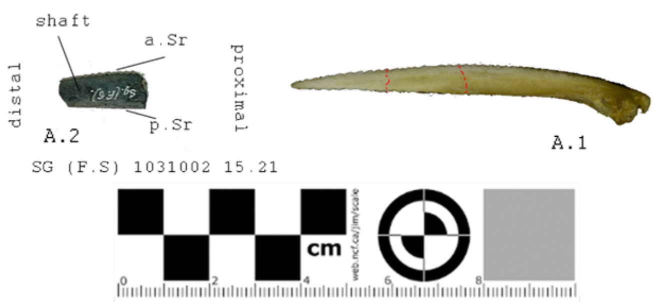

Figure 6. Pectoral spine fossil (A.2) of *Pangasius* sp. with a recent specimen as a comparison (A.1). a.Sr = Anterior serration, p.Sr=Posterior Serration.

Material examined: A pectoral spine collection of Bandung Geological Museum, Sangiran's finding.
Diagnostic characters: The pectoral spine is very flat and has a very smooth shaft. With a very small and relatively blunt serration compared to other species (Figure 6, SG (F.S) 1031002 15.21).

Material examined: 4 specimens of pectoral spine collection of Laboratory of Bioanthropology and Paleoanthropology UGM, 41 specimens of pectoral spine collection of Sangiran Early Man Site along with 1 piece of operculum, 19 specimens of pectoral spine collection of Bandung Geological along with 7 fragments of neurocranium. In 1876, this species was found in Padang (Figure 8).

Diagnostic characters: The part of the shaft located near the dorsal process of this species has a long indentation toward distal-anterior direction. On the dorsal side of the shaft is covered a small serration, then leads posteriorly toward a narrow groove that borders posterior serration. Whereas the ventral side is identical to the dorsal side but the groove is even narrower (Figure 7, SA 270778). Neurocranium tends to be flat dorso-ventrally like *Hemibragus nemurus* but is less ornamentative (Figure 7, K 1530 + K 1528). Rounded premaxilla like sickles (Figure 7, K 1526) and large operculare are trapezoidal with cavity near dorsal (Figure 7, PIS. 0026).

SISORIDAE Bleeker, 1858
Bagarius gigas Günther, 1876

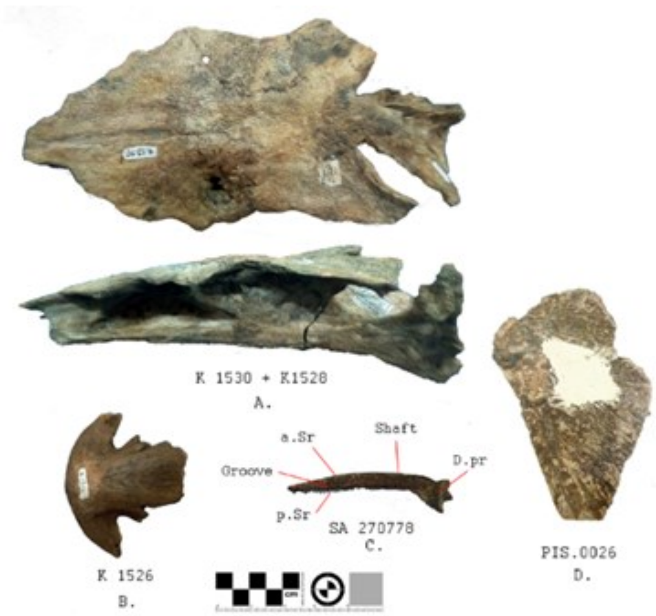

Figure 7. Fossils of (A) Nearly intact Neurocranium, (B) Premaxilla, (C) Pectoral spine, and (D) Opercularum of *Bagarius gigas*. a.Sr = Anterior serration, p.Sr=Posterior Serration, D.Pr=Dorsal Process.

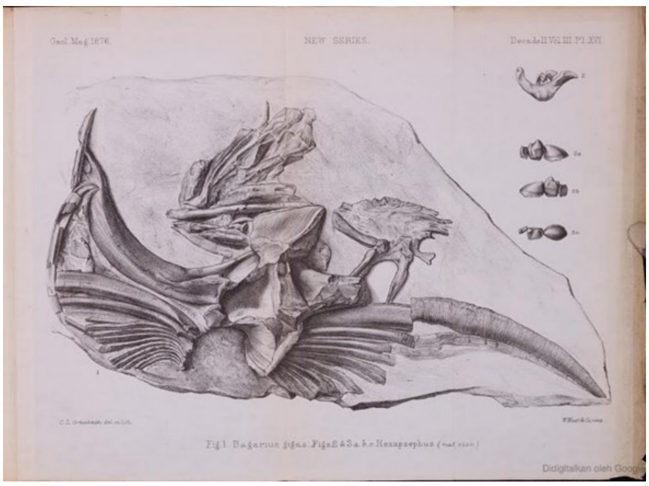

Figure 8. *Bagarius gigas* fossil, Günther, 1876 findings in Padang.

BAGRIDAE Bleeker, 1858
Hemibragus nemurus (Valenciennes, 1840)

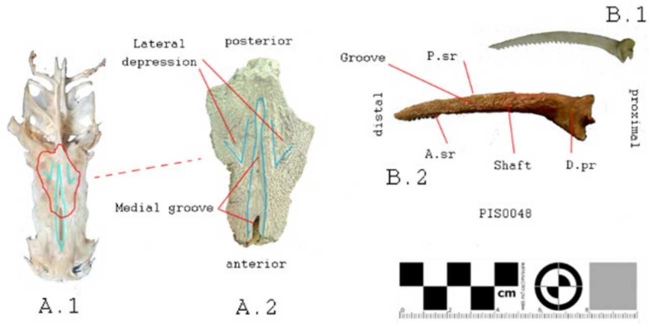

Figure 9. Fossils (A.2) fragments of Neurocranium and (B.2) pectoral spine of *Hemibragus nemurus* species compared with recent specimens of neurocranium (A.1) and pectoral spine (B.1). a.Sr = Anterior serration, p.Sr=Posterior Serration, D.Pr=Dorsal Process.

Material examined: 5 pectoral spines and 1 neurocranium fragment collection of the LBP UGM. Twenty four specimens of pectoral spine collection of the SEMS and 21 specimens of pectoral spine along with 1 fragment of neurocranium collection of the BGM.

Diagnostic characters: The shaft located near the dorsal process tends to be straighter, while the posterior part folds inward. The dorsal and ventral sides are relatively identical, the anterior and posterior sections are covered with serration, while its medial is covered with a fairly broad groove (Figure 9, PIS0048). The neurocranium is found to have lateral V-shaped depression upside down and medial groove along the central side of the neurocranium (Figure 9, A).

CYPRINIFORMES Bleeker, 1859
CYPRINIDAE Bleeker, 1859
Osteochilus vittatus (Valenciennes, 1842)

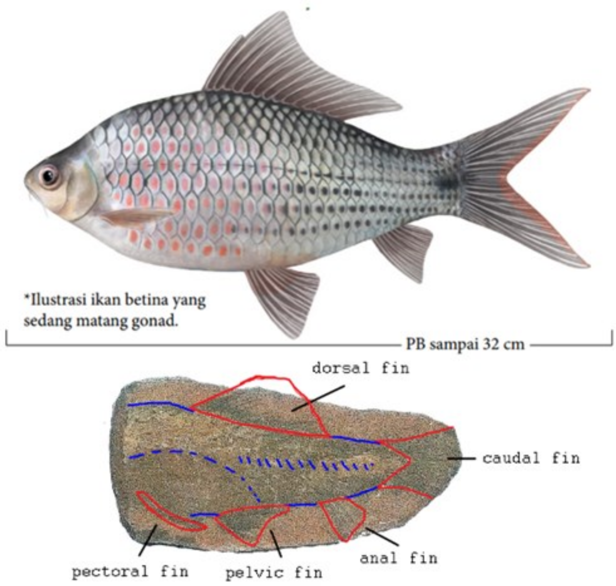

Figure 10. *Osteochilus vittatus* barb fossils in a stone plate show pectoral, pelvic, anal, caudal, and dorsal fins. The comparative figure is taken from Sukmono *et al.* (2017).

Material examined: 3 specimens of body parts cut off posteriorly and anteriorly in rocks.

Diagnostic characters: Latero-laterally flat body, hydrodynamically taper. In the anteriorly cut specimen, the dorsal, anal, and pectoral fins are sharp triangle in shape. The base of posterior dorsal fin must be opposite to anterior base of anal fin (Figure 10). Headpieces of moderate size compared to body proportions, unpreserved fins and body size generally differed drastically from both pieces it is possible that these three specimens were members of different types even though they were found in the same location.

PERCIFORMES Bleeker, 1863
SPHYRAENIDAE Rafinesque, 1815
Sphyraena crassidens (De Beaufort, 1926)

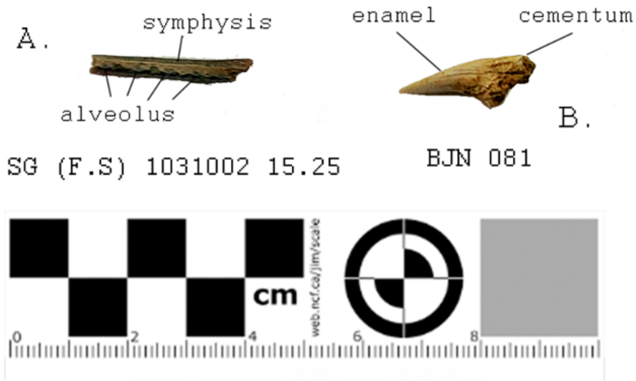

Figure 11. The jaw fossils of the *Sphyraena crassidens* species show the presence of a tooth gap alveolus and symphysis (A.) and sharply curved teeth with thin serration on the enamel surface (B.).

Material examined: 2 pieces of jaw specimens and a tooth.

Diagnostic characters: The jaws are thin and straight, with clear tooth sockets (Figure 11, SG (F.S) 1031002 15.25). The teeth are long, curved proximally with a very small serration on the sides of the teeth (Figure 11, BJN 081).

Material examined: 20 pieces of operculare and 1 piece of suboperculare collection of the Bandung Geological Museum.

Diagnostic characters: The operculare plate is the bony part of the operculum. The operculare and suboperculare pieces have an identical structure, thin in shape but very compact in structure with wrinkles on lateral surface and spurs at the posterior end of the operculare plate (Figure 12).

ANABANTIFORMES Britz, 1995
ANABANTIDAE Bonaparte, 1831
Anabas testudineus (Bloch, 1792)

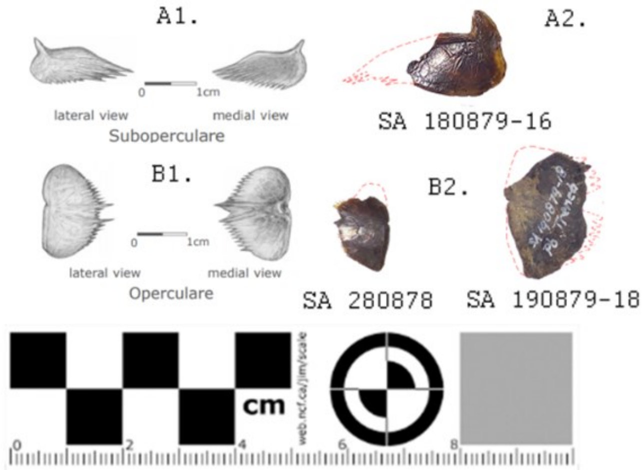

Figure 12. Operculare (B.2) and Suboperculare (A.2) fossils of *Anabas testudineus* perch with comparison from Voeun (2006) (A.1 & B.1).

Paleo-Environmental Implications

From the oldest site on the island of Java (Table 2); Cijurey in the southern Cirebon region found *Hemibragus nemurus* and many whale bones (not included in this study) indicate a lowland stream and estuary or mangrove swamps environment. This site has identical age to Satir faunal group in Bumiayu, Central Java when the island of Java was still a small island covered by mangroves during the Lower Pleistocene 1.5 to 1.2 million years ago (Louys *et al.*, 2007).

On the Sangiran site, divided into three layers which have different age respectively; Sangiran Black Clay, Sangiran Grenzbank, and Sangiran Kabuh (Laporte, 1990). The Sangiran Black Clay layer has an age that is identical to the Satir fauna group and the Cijurey site according to Laporte (1990). On this site, *Bagarius gigas* species were found to live in swamps that have short vegetation.

Next in the Sangiran Grenzbank layer which is identical to the H.K Trinil faunal group aged 1 million years ago in the Lower-Middle Pleistocene. In this layer, *Clarias macrocephalus* started to roam in lowland and wetland rivers. The Sangiran layer which is located above Grenzbank is Kabuh but no fossils of fish were found in this layer.

This study also found fossils on the Sangiran site with unclear layer of origin, namely; *Bagarius gigas*, *Hemibragus nemurus*, *Clarias macrocephalus*, Ariidae indeterminate, *Plotosus canius*, *Clarias batrachus*, *Sphyraena crassidens*, *Anabas testudineus*, and Pangasiidae indeterminate.

The existence of fish associated marine waters such as *Plotosus canius* and *Sphyraena crassidens*, fish that live in swamps/mangroves such as *Bagarius gigas*

Table 2. Actinopterygii fossil findings on several sites on Java and their age (Hardjasasmita, 1987; Theunissen *et al.*, 1990; Storm, 1995; Aziz *et al.*, 1999; Louys *et al.*, 2007; Cohen *et al.*, 2013; Arif *et al.*, 2014; Jayanti *et al.*, 2017).

	← Older								Younger →
Age	Plio-Pleistocene	Lower Pleistocene	Lower Pleistocene	Middle-Lower Pleistocene	Pleistocene	Pleistocene	Upper-Middle Pleistocene	Upper-Middle Pleistocene	Holocene
	-	1.5 – 1-2 m.y.a.	1.5 - 1.2 m.y.a.	1.0 m.y.a.	1.5 – 0.8 m.y.a.	-	550-140 m.y.a.	550-140 m.y.a.	10-5 m.y.a.
Site / Species	Kalitidu	Cijurey	Sangiran Black Clay	Sangiran Grenzbank	Sangiran *assorted*	Cipatik/ Cililin	Watualang	Sidoredjo (Ngandong)	Gua Lowo (Sampungian Site)
Bagarius gigas			✓		✓		✓		
Hemibragus nemurus		✓			✓			✓	✓
Clarias macrocephalus				✓	✓				
Ariidae					✓				
Plotosus canius					✓				
Sphyraena crassidens	✓				✓				
Anabas testudineus					✓				
Clarias batrachus					✓				
Pangasiidae					✓				
Osteochilus vittatus						✓			

and fish that live in freshwaters such as *Clarias batrachus* and *Anabas testudineus* show the environment of downstream river and estuary which was separated from the sea by swamps or mangroves.

In the ancient Bengawan Solo River, there were several excavation areas which were found Actinopterygii fish fossils, namely; Kalitidu, Watualang, Sembungan, and Pandean, Sidoredjo and Gua Lowo. At the Kalitidu Site, Bojonegoro, East Java, aged Plio-Pleistocene, a species of marine barracuda fish, *Sphyraena crassidens* were found. This fish was also discovered by de Beaufort in its publication "A collection of marine fishes from the Miocene of South Celebes in Maros, Sulawesi". This finding indicated this site originally in the sea or adjacent to the sea.

On other sites along the ancient Bengawan Solo River, in Watualang, Sembungan and Pandean were found *Bagarius gigas* cranium. The environment at this time showed a river that was close to a wetland swamp but not completely in the sea. This layer is younger than the Kaltidu site aged Middle-Upper Pleistocene.

In Bellwood, 2017 the Ngandong and Watualang sites were known to have the same age. Using Uranium radioactive age measurement, the age of both sites were dated 550 to 140 thousand years ago.

On the Sidoredjo site which on the formation with Ngandong at the edge of the ancient Bengawan Solo stream were found *Hemibragus nemurus* fossils and members of Clariidae that are different from the other species found in this study. Probably at this time the Bengawan Solo was flowing slowly and had a wide riverbank due to the presence of *Hemibragus* fish fossils. Not much has changed from the previous period at the Watualang, Sembungan, Pandean site which tends to show the estuary river ecosystem near the mangrove swamp.

On the Gua Lowo site, which is part of the Sampung Site which has the youngest age in the ancient Bengawan Solo River aged 10-5 thousand years ago at the time of the Holocene. According to Storm (1995), the ancient Bengawan Solo River ecosystem was a Tropical Rain Forests. However, from the fish fossils found, *Hemibragus nemurus* shows the wide river waters with slow currents, not much different from the Sidoredjo site which has an adjacent age, even from Watualang.

On the Cipatik/Cililin site which used to be part of the ancient Bandung lake, found fossils of *Osteochilus vittatus* barb fish. The existence of this type of fish shows the calm Lake Bandung environment, and full of vegetation as the substrate for dwelling. Far different from other sites that tend to show the ecosystem of river estuaries.

CONCLUSION

Found at least 8 species of actinopterygians fish fossils in Java which belong to three orders. Those species are: *Bagarius gigas, Hemibragus nemurus, Clarias macrocephalus,* Ariidae indeterminate, *Plotosus canius, Clarias batrachus*, and Pangasiidae indeterminate from the order Siluriformes; *Anabas testudineus* and *Sphyraena crassidens* from the order Perciformes; and *Osteochilus vittatus* from the order Cypriniformes. Based on the fossil findings showed that Java Island during the Plio-Pleistocene used to be a marine environment that gradually became a lowland river close to mangrove swamps and estuaries. On the ancient Bandung lake site was a lacustrine environment that has a calm flow and is overgrown with riparian vegetation.

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