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Fish diversity of the Bengawan Solo River estuary, East Java, Indonesia

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Abstract. *Hasan V, Andraini NE, Isroni W, Sari LA, Nafisyah AL, Dewi NN, Putri DNA, Prasasti TAB, Ramadhani AA, Daniel K, South J, Vieira LO, Ottoni FP, Maftuch, Faqih AR, Wirabuana PYAP, Tamam MB, Valen FS. 2023. Fish diversity of the Bengawan Solo River estuary, East Java, Indonesia. Biodiversitas 24: 2207-2216.* Bengawan Solo River is the longest river in Java which flows from Mount Lawu and empties into the North Coast of Java. The watershed is a hot spot for fish species diversity, especially in the estuary area. The purpose of this study was to initiate an inventory of fish species, their abundance, and biodiversity assessment based on the Shannon diversity index (H'), evenness index (E), and dominance index (C) in one of the Bengawan Solo River estuary, namely Brondong Sub-district, Lamongan District, East Java, Indonesia. The research was conducted from September to November 2022 at three stations with different ecological types and environmental conditions. Fish sampling was carried out using a gill net attached to a boat. In this study, 44 fish species from 22 families were identified. The highest abundance of fish was obtained from the Ariidae family, namely the Spotted sea catfish *Arius maculatus* (Thunberg, 1792) and Sagor catfish *Hexanematichthys sagor* (Hamilton, 1822). The fish diversity index obtained was 1.2-3.01, the uniformity index obtained was 0.7-0.92, and the dominance index obtained was 0.07-0.33. The H', E, and C at Station 2 have higher values than the other stations. The diversity expressed in H' values at the three research stations indicates that the mangrove in the Bengawan Solo River estuary area has a high diversity of fish species.

Keywords: Aquatic environment, brackish water, fisheries, life below water

INTRODUCTION

Indonesia is one of the countries contributing the highest fish production in the world, at 8.2% of global fish production (FAO 2022). Fish are an extremely diverse group of vertebrates, corresponding to more than 50% of all vertebrate species, occurring in almost all aquatic environments worldwide (Nelson et al. 2016). In Indonesia, there are more than 8.500 fish species, which are classified based on the characteristics of the habitats they occur (e.g., saltwater, brackish, and freshwater) (Gani et al. 2021; Hasan et al. 2021a; Ndobe et al. 2022). The fisheries and aquaculture sectors are important in developing the regional and national economy (Budiasa et al. 2018; Hastuti et al. 2020). In addition, they provide important services, such as raw materials for industries, people's livelihoods, foreign exchange sources through the export of fishery products, and other services (Prehadi et al. 2015; Pratama et al. 2020).

Aquatic environments are strongly influenced by conditions, such as salinity, water flow, kind of substrate, plants living in the aquatic habitat, exposure to sunlight, water turbidity, and temperature, impacting and modifying the diversity of fish species that occur in that environments (Dudgeon et al. 2006; Islamy and Hasan 2020; Hasan et al. 2022a; Isroni et al. 2023). The sustainability of aquatic species will be greatly influenced by human activities around the waters, directly and indirectly (Hasan et al. 2019a; Hasan et al. 2021e). Human activities such as habitat modification, overfishing, the introduction of alien species, and natural causes such as sea level rise and global climate change can pose several threats to the ichthyofauna diversity of an area of water (Hasan and Widodo 2020; Kusumah et al. 2023). One water area with high fishery potential is the estuary (Ridho et al. 2021; Hasan et al. 2022b; Valen et al. 2022a).

Estuaries are the most productive water areas with unique and complex ecosystems with various habitats (Rimelahas et al. 2022). Aquatic animals of varying degrees depend heavily on estuary ecosystems, especially for spawning and nursery grounds (Asriyana et al. 2021). Habitat heterogeneity causes this area to be rich in resources, with the largest component being the fish fauna.

Fish that generally live in estuary waters have a high tolerance for fluctuations in salinity and can move from low-salinity rivers to high-salinity seas (Hasan and Islam 2020; Hasan et al. 2021b).

Bengawan Solo River estuary is one of the areas with great potential in the fisheries sector. This is the longest river in Java, Indonesia which originates in the Lawu Mountains of Central Java and empties into the north coast of East Java (Kusumastuti et al. 2020). The first estuary is in Brondong Sub-district, Lamongan District, and the second is in Ujungpangkah Sub-district, Gresik District, East Java Province (Sari et al. 2016). Like most Javanese river systems, the length of the Bengawan Solo River is subject to high anthropogenic pressure, including fisheries for human consumption (Valen et al. 2020). The Bengawan Solo River is crucial for the community because it is the largest supplier of raw water for the main district in Java. In addition, the utilization of capture fisheries along the river flow contributes to the welfare of the people whose livelihood are fishermen (Sari et al. 2016).

There is limited data on the recent fish species assemblage of the Bengawan Solo River estuary. Fish inventories are essential baseline research for conservation management as diversity patterns indicate ecosystem health and the data can be used to infer the impact of stressors (Porobic et al. 2019; Li et al. 2021). This information is crucial for conservation programs, such as domestication or the creation of fish sanctuary sites and the development of sustainable fisheries management policy to support socio-ecological systems. In addition, research on fish diversity is very helpful for detecting fisheries productivity in these waters (Liang and Pauly 2017).

MATERIALS AND METHODS

Sampling site

The study was conducted in the Bengawan Solo River estuary, Brondong Sub-district, Lamongan District, East Java, Indonesia, from September to November 2022 (Figure 1). The sampling locations were selected by purposive sampling based on different ecological types and environmental conditions (Table 1).

Water quality

The water quality parameters temperature (°C), pH, dissolved oxygen (ppm), and salinity (ppt) were measured at each location immediately after specimen collection. The water conditions of each collecting site are listed in Table 2.

Fish collection and species identification

Fish sampling was assisted by 2 fishermen using 1 gillnet, 2 lending nets (mesh size of 2.5 cm), and 10 medium hooks, organized in semicircular shape at each station. The sampling was conducted twice per month from September to November 2022. The specimens collected at each station were counted and photographed in the field every three months. After collection, the specimens were preserved in a 7% formalin solution (Hasan et al. 2019b), labeled according to the local name, station, and collection date, and transported to the laboratory for identification. Fish were identified using manuals from Allen (1999), White et al. (2013), and Froese and Pauly (2022). The species names, authors and year of publication, geographic distribution, and families were checked in Fricke et al. (2023).

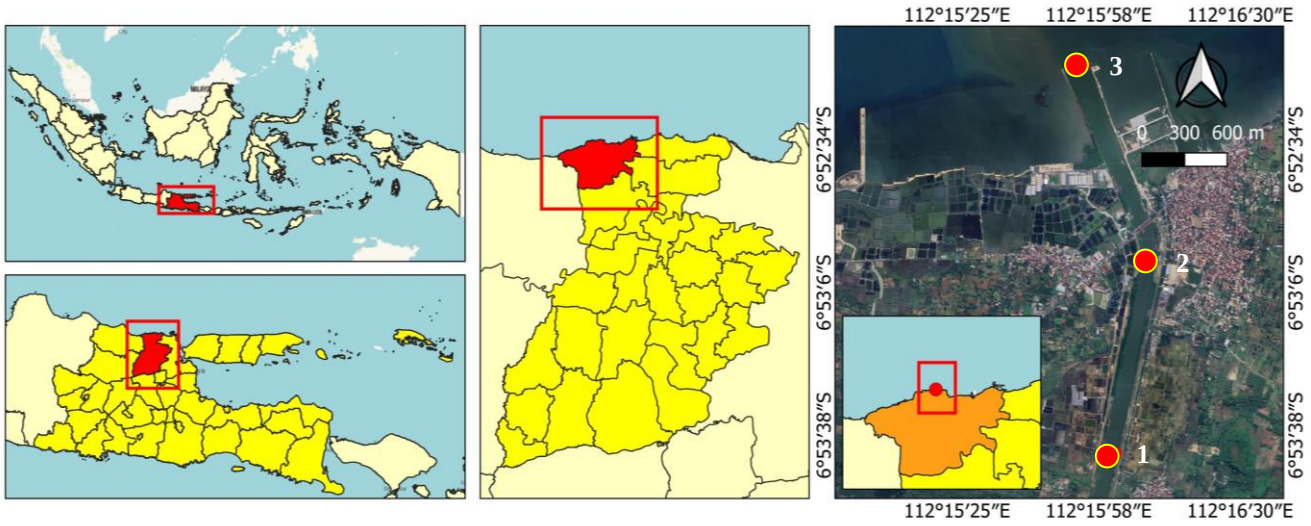

Figure 1. Collecting sites in the Bengawan Solo River estuary, Brondong Sub-district, Lamongan District, East Java, Indonesia. Station 1. Lower river section, Station 2. Mangrove forest, Station 3. Intertidal zone

Table 1. Coordinates and description of the sampling sites

Station	Coordinates	Site description	Vegetation
1	6°53'42.5"S, 112°16'01.4"E	Lower river section, close to shrimp ponds	*Nypa*
2	6°52'58.9"S, 112°16'09.1"E	Mangrove forest, close to shipping dock	*Avincenia*, *Bruguiera*, *Rhizophora*
3	6°52'14.5"S, 112°15'53.9"E	Intertidal zone, close to the fish port	There are no standing plants, only seagrasses and seaweeds

Table 2. Water parameters at each collecting site (station)

Parameters	Equipment	Station 1	Station 2	Station 3
Temp. (°C)	Thermometer	29.5-32.5	31.8-32.1	31.3-32.3
pH	pH meter	7.68-7.70	7.65-7.78	7.62-8.04
DO (ppm)	DO meter	7.76-10.06	8.0-8.16	7.9-8.16

Data analysis

The number of specimens (N), species composition, diversity, evenness, and dominance were compared between sampling stations and analyzed descriptively. The Shannon diversity index (H') was used to estimate the diversity of fish species:

$$H' = -\sum \left(\frac{ni}{N}\right) In \left(\frac{ni}{N}\right)$$

Where:

H' : Shannon diversity index

ni : proportion of the entire community consisting of species i and ln : natural log

Evenness (E) was used to describe the similarity in the abundance of different species in a community:

$$E = \frac{H'}{\ln S}$$

Where:

E : Evenness index

H' : Shannon diversity index

ln S : natural log of the total number of unique species

Dominance (C) was used to describe the presence of a dominating species in a community:

$$C = \sum \left(\frac{ni}{N}\right)^2$$

Where:

C : Dominance index

ni: proportion of the entire community consisting of species i

RESULTS AND DISCUSSION

Fish species found from Bengawan Solo River Estuary

A total of 44 species of 31 genera were collected, belonging to 22 families (Table 3). The morphological features of each species are presented in Table 4. The most abundant species in this study were *Arius maculatus* and *Hexanematichthys sagor* (both belonging to the Family Ariidae). Most of the collected specimens were sub-adult or adult, which may be related to the size of the nets used in this study. All fishes caught are native, and no foreign fishes were found during samplings, such as tilapia and other exotic fish (Hasan et al. 2020a; Hasan et al. 2020b; Insani et al. 2020; Serdiati et al. 2020). That indicates the estuary ecosystem of the Bengawan Solo River estuary is still maintained (Hasan et al. 2020c; Mangitung et al. 2021; Serdiati et al. 2021).

The check list

Acanthurus xanthopterus (Valenciennes, 1835)

One dark spine on caudal peduncle; 25-27 dorsal-fin rays; caudal fin crescent-shaped brownish gray with faint bluish-gray outline; and white ring at the base of the caudal fin.

Arius maculatus (Thunberg, 1792)

Body gray-black, with 10-13 yellow vertical stripes; one dorsal-fin spine and seven dorsal-fin rays; caudal fin forked, 16-30 anal fin rays.

Hexanematichthys sagor (Hamilton, 1822*)*

Dorsal and pectoral fins with serrated spines; 7 dorsal-fin rays; 11 pectoral-fin rays; 6 ventral-fin rays; 18-19 anal-fin rays; caudal fin forked; and head flattened to snout, with three pairs of barbels.

Turrum coeruleopinnatus (Rüppell, 1830*)*

Sharp scales on caudal peduncle; head curved to nape; 20-23 dorsal-fin soft rays; fins pale yellowish; caudal din forked; and faint yellowish-orange spots on flanks.

Cynoglossus puncticeps (Richardson, 1846)

Mouth behind the tip of snout; eyes separated; scales on both sides of the body serrated; and fins with narrow black stripes.

Paraplagusia bilineata (Bloch, 1787)

81-88 anal-fin rays; >105 dorsal-fin rays; two lateral lines on the eyed side; and body brown with numerous irregular whitish-yellow patches on the eyed side.

Brevitrygon javaensis (Last & White, 2013)

The body is yellowish brown; tail is longer than the body; the body is depressed; and the pectoral fins widened and fused with the left and right sides of the head.

Sardinella gibbosa (Bleeker, 1849)

Body compressed; thick scales on belly prominent, last two anal-fin rays enlarged; ventral fin with one ray unbranched and 7 others branched; golden stripe on sides of the body; and dark patch at base of the dorsal fin.

Prionobutis microps (Weber, 1907)

Small flat head and body cylindrical; gray to brown coloration with white markings on flanks; five dark brown to gray stripes radiating from eyes; and pectoral fins and caudal fin with dark bands.

Cephalopholis boenak (Bloch, 1790)

Dorsal fin with 9 spines and 15-17 rays, caudal fin rounded, 8 anal-fin rays, body brownish with 7 or 8 darker stripes, spots on opercles, some fins with white edges.

Epinepelus coioides (Hamilton, 1822)

Body with 5 faint dark stripes. 11 dorsal-fin spines, caudal fin rounded, 58-65 lateral-line scales, head and body pale brown mottled with many small orange-brown spots, fins mottled.

Epinephelus malabaricus (Bloch & Schneider, 1801)

Body light brown with 5-6 dark brown stripes and many black spots on the body.11 dorsal fin spines and 14-16 soft rays, 3 anal fin spines and 8 soft rays, caudal fin rounded, 54-64 lateral line scales.

Table 3. Fish species found in the Bengawan Solo River estuary, Indonesia

Family	Species	Local name	Station		
			1	2	3
Acanthuridae	*Acanthurus xanthopterus*	*Lodem*	-	+	-
Ariidae	*Arius maculatus*	*Lundu*	+	+	+
	Hexanematichthys sagor	*Dukang*	+	+	+
Carangidae	*Turrum coeruleopinnatus*	*Kuwe bintik*	-	+	+
Cynoglossidae	*Cynoglossus puncticeps*	*Lidah*	-	+	-
	Paraplagusia bilineata	*Lendra*	-	+	+
Dasyatidae	*Brevitrygon javaensis*	*Pari*	-	+	+
Dorosomatidae	*Sardinella gibbosa*	*Tembang*	-	+	-
Eleotridae	*Prionobutis microps*	*Gobi*	+	+	+
Epinephelidae	*Cephalopholis boenak*	*Kerapu*	-	-	+
	Epinepelus coioides	*Kerapu*	-	+	-
	Epinephelus malabaricus	*Kerapu Lumpur*	+	+	-
	Epinephelus areolatus	*Kerapu*	-	-	+
	Epinephelus erythrurus	*Kerapu*	-	+	-
	Epinephelus faveatus	*Kerapu*	-	+	+
	Epinephelus lanceolatus	*Kerapu*	-	+	+
	Epinephelus quoyanus	*Kerapu Tutul*	-	-	+
Gerreidae	*Gerres oblongus*	*Kapas-kapas*	-	+	+
Gobiidae	*Acentrogobius viridipunctatus*	*Gelodok*	+	+	+
Haemulidae	*Diagramma pictum*	*Gajih*	-	+	+
Labridae	*Halichoeres margaritaceus*	*Supitai*	-	+	+
Lutjanidae	*Lutjanus decussatus*	*Kakap*	-	+	-
	Lutjanus fulviflamma	*Kembang Waru*	-	+	+
	Lutjanus russellii	*Tembelon*	-	+	+
	Lutjanus madras	*Kakap*	-	+	+
Monodactylidae	*Monodactylus argenteus*	*Gebal*	-	+	-
Mugilidae	*Crenimugil seheli*	*Belanak*	-	-	+
	Ellochelon vaigiensis	*Belanak Jumpul*	+	+	-
Muraenidae	*Gymnothorax tile*	*Belut muara*	-	+	+
Polynemidae	*Eleutheronema tetradactylum*	*Kurau*	-	+	+
Pomacentridae	*Abudefduf bengalensis*	*Tibok*	-	-	+
	Pomacentrus tripunctatus	*Tibok*	-	+	+
Scatophagidae	*Scatophagus argus*	*Kiper*	+	+	+
Sciaenidae	*Dendrophysa russelii*	*Kambing-kambing*	+	+	-
	Johnius carouna	*Diles*	-	+	-
	Johnius heterolepis	*Diles*	-	+	+
	Johnius macropterus	*Diles*	-	+	+
	Nibea soldado	*Tigawaja*	-	+	-
Scorpaenidae	*Scorpaenopsis ramaraoi*	*Kerapu batu*	-	+	-
	Parascorpaena picta	*Lepu Karang*	-	+	+
Siganidae	*Siganus canaliculatus*	*Baronang Lada*	-	+	-
	Siganus javus	*Baronang*	-	-	+
	Siganus virgatus	*Baronang*	-	+	+
Soleidae	*Dagetichthys commersonnii*	*Kleket*	-	+	-

Epinephelus areolatus (Forsskål, 1775)

Dorsal fin 11 spines and 15-17 soft rays, caudal fin upright, 47-52 lateral-line scales, completely covered with closely arranged yellowish-brown spots.

Epinephelus erythrurus (Valenciennes, 1828)

Dorsal fin with 11 spines and 15-17 rays, anal fin with 3 and 8 rays, body blackish brown with lighter to white spots, caudal fin slightly rounded.

Epinephelus faveatus (Valenciennes, 1828)

Dorsal fin with 11 spines and 16-18 soft rays, caudal fin rounded, 48-52 lateral-line scales, body light brown with densely spaced brown spots of unequal size, fins mostly yellowish between spots, head dark.

Epinephelus lanceolatus (Bloch, 1790)

Body and head are elongated and flattened, body is brownish with lots of white spots, fins are yellow with brown spots, dorsal fin has 11 spines and 14-16 soft rays, anal fin has 3 spines and 8 soft rays.

Epinephelus quoyanus (Valenciennes, 1830)

Body covered with hexagonal spots. Dorsal fin has 11 spines and 16-18 soft rays, anal fin has 3 spines and 8 soft rays, caudal fin is rounded, with 48-52 lateral line scales.

Gerres oblongus (Cuvier, 1830)

Caudal fin forked; dorsal fin with 9-10 spines; anal fin with 10 rays; pectoral fin with 7-12 rays and fins yellowish hyaline.

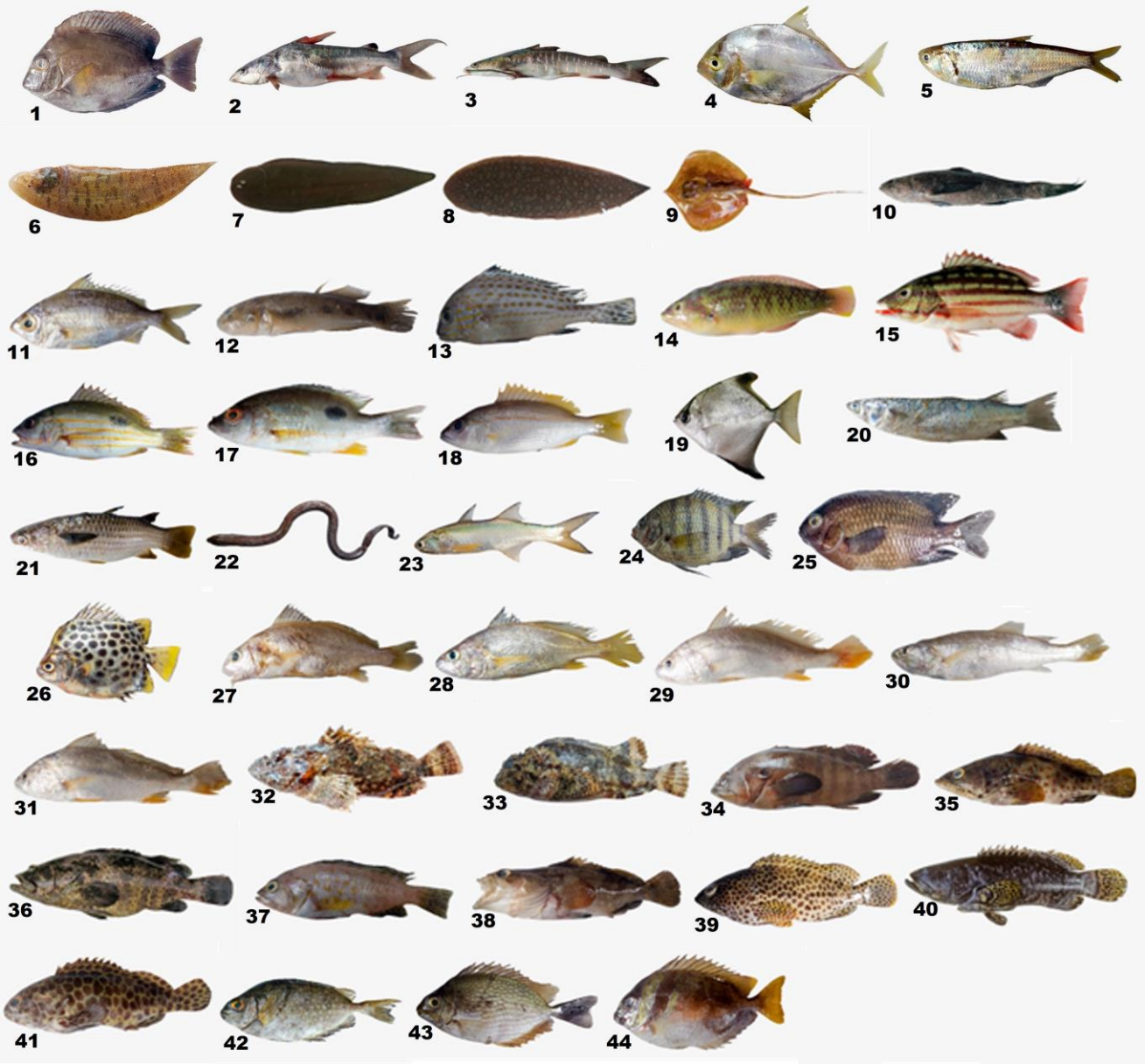

Figure 2. Fishes on the Bengawan Solo River Estuary: 1. *Acanthurus xanthopterus*; 2. *Arius maculatus*; 3. *Hexanematichthys sagor*; 4. *Turrum coeruleopinnatus*; 5. *Sardinella gibbosa*; 6. *Cynoglossus puncticeps*; 7. *Dagetichthys commersonnii*; 8. *Paraplagusia bilineata*; 9. *Brevitrygon javaensis*; 10. *Prionobutis microps*; 11. *Gerres oblongus*; 12. *Acentrogobius viridipunctatus*; 13. *Diagramma pictum*; 14. *Halichoeres margaritaceus*; 15. *Lutjanus decussatus*; 16. *Lutjanus fulviflamma*; 17. *Lutjanus russellii*; 18. *Lutjanus madras*; 19. *Monodactylus argenteus*; 20. *Crenimugil seheli*; 21. *Ellochelon vaigiensis*; 22. *Gymnothorax tile*; 23. *Eleutheronema tetradactylum*; 24. *Abudefduf bengalensis*; 25. *Pomacentrus tripunctatus*; 26. *Scatophagus argus*; 27. *Dendrophysa russelii*; 28. *Johnius carouna*; 29. *Johnius heterolepis*; 30. *Johnius macropterus*; 31. *Nibea soldado*; 32. *Scorpaenopsis ramaraoi*; 33. *Parascorpaena picta*; 34. *Cephalopholis boenak*; 35. *Epinephelus coioides*; 36. *Epinephelus malabaricus*; 37. *Epinephelus areolatus*; 38. *Epinephelus erythrurus*; 39. *Epinephelus faveatus*; 40. *Epinephelus lanceolatus*; 41. *Epinephelus quoyanus*; 42. *Siganus canaliculatus*; 43. *Siganus javus*; 44. *Siganus virgatus*

Acentrogobius viridipunctatus (Valenciennes, 1837)

Body brown with black markings. Caudal fin is rounded, the pectoral fins are hyaline, and the dorsal and caudal fins are blackish-brown.

Diagramma pictum (Thunberg, 1792)

Dorsal fin with 9-10 spines, adults blue-gray with many small brownish-orange spots, dorsal and caudal fins with dark spots, juveniles black with two whitish stripes.

Halichoeres margaritaceus (Valenciennes, 1839)

Dorsal fin with 9 spines and 11 soft rays, anal fin with 3 spines and 11 soft rays, body greenish to brownish with 4-6 faint vertical dark stripes, horizontal pink line under the eye.

Lutjanus decussatus (Cuvier, 1828)

Dorsal fin has 10 spines and 13-14 soft rays, anal fin has 3 spines and 8-9 soft rays. Body is yellowish-white

with reddish fins, 5-6 red and black horizontal stripes on the base of the tail.

Lutjanus fulviflamma (Forsskål, 1775)

Dorsal dark brown and yellowish White on the body, with 6-7 yellow stripes on the sides. Dorsal fin has 10 spines and 13-14 rays, anal fin has 3 spines and 8 rays, black spot is under the dorsal fin.

Lutjanus russellii (Bleeker, 1849)

7 or 8 faint golden brown stripes on the sides, black spots mostly over the lateral line, dorsal and caudal fins reddish, dorsal fin has 10 spines and 14 soft rays, anal fin has 3 spines and 8 rays.

Lutjanus madras (Valenciennes, 1831)

Midlateral stripe on the body is not wider or darker than other stripes, body with yellow stripes below the lateral line, dorsal fin has 10 spines and 13 soft rays, anal fin has 3 spines and 9 soft rays.

Monodactylus argenteus (Linnaeus, 1758)

Body oval and very flattened, mouth small, no ventral fins, body silvery and blackish yellow on dorsal fin tip, dorsal fin has 7-8 spines and 27-31 soft rays; anal fin has 3 spines and 27-32 soft rays.

Crenimugil seheli (Fabricius, 1775)

Body silvery, blue or brownish green above, dorsal fin has 4-5 spines and 8-9 soft rays; anal fin has 3 spines and 8-10 soft rays, pectoral, anal, and ventral fins are yellow.

Ellochelon vaigiensis (Quoy & Gaimard, 1825)

Caudal fin is upright yellow, with 25-29 scales arranged longitudinally, silvery-white greenish brown above, dorsal fin has 4 spines and 9-10 soft rays, anal fin has 3 spines and 7-9 soft rays.

Gymnothorax tile (Hamilton, 1822)

Blackish brown, pointed tail, body moderately elongated, cylindrical in front, compressed along tail; eyes small; teeth very sharp, more or less in two rows, inner series larger.

Eleutheronema tetradactylum (Shaw, 1804)

Body elongated, base of pectoral fin far below body midline, 71-80 lateral-line scales, 9-12 scale rows above lateral line, dorsal fin with 9 spines and 13-15 soft rays, anal fin with 3 spines and 14-16 soft rays.

Abudefduf bengalensis (Bloch, 1787)

19-23 lateral-line tube scales, dorsal fin with 13 spines and 13-15 rays, caudal fin forked with rounded tip, bluish-grey to dark greenish with 5 or 6 blackish stripes on sides, dorsal fin tip black.

Pomacentrus tripunctatus (Cuvier, 1830)

17-18 lateral-line tube scales, dorsal fin with 13 spines and 14-15 rays, caudal fin forked with broadly rounded tip, evenly dark brown, black spot on the upper of caudal peduncle.

Scatophagus argus (Linnaeus, 1766)

Body with black spots about pupil size, fins in adults yellowish, juvenile reddish. Very broad body, adults with a deep notch on the head above eyes, 10-11 dorsal-fin spines and 16-18 soft rays, 3-4 spines, and 13-15 anal-fin rays.

Dendrophysa russelii (Cuvier, 1829)

Body is yellowish silver, and fins are yellow to orange. Dorsal fin has 11 spines and 25-28 soft rays. The anal fin has 2 spines and 7 soft rays, and a barbell on the chin.

Johnius carouna (Cuvier, 1830)

Body silvery, fins mostly yellowish. Dorsal fin with 11 spines and 26-30 rays, anal fin with 2 spines and 7 rays, caudal fin sharp, no barbell on the chin.

Johnius heterolepis (Bleeker, 1873)

Body silvery and bluish or green above, fins yellowish. Dorsal fin with 11 spines and 25-28 rays, anal fin with 2 spines and 7 rays, caudal fin very sharp, no barbell on the chin.

Johnius macropterus (Bleeker, 1853)

Body silvery brown, fins blackish to yellowish. Dorsal fin has 11 spines and 29-34 soft rays, and the anal fin has 2 spines and 7 soft rays; the caudal fin is slightly sharp, with small stiff antennae on the chin.

Nibea soldado (Lacepède, 1802)

Dorsal fin has 10-11 spines and 27-33 soft rays; the anal fin has 2 spines and 7 soft rays; the snout is rounded, body color is silver with orange pectoral, ventral, anal, and caudal fin.

Scorpaenopsis ramaraoi (Randall & Eschmeyer, 2002)

Head broad and flat, snout long; dorsal fin has 12 spines and 9 rays; anal fin has 3 spines and 5 rays; the body is brown, and fins are white with reddish-brown stripes.

Parascorpaena picta (Cuvier, 1829)

Head broad and slightly flattened, snout short, dorsal fin with 12 spines and 9-10 rays, anal fin with 3 spines and 5 rays, body brown, fins white with brown stripes.

Siganus canaliculatus (Parque, 1797)

Pectoral, pelvic fins without scales, dorsal and anal fin spines slender, caudal fin margin emarginate to slightly forked, silvery-gray to greenish with many white spots.

Siganus javus (Linnaeus, 1766)

The ventral area in front of pelvic fins is scaly, body broad, caudal fin emarginate, brownish-grey above with many pale bluish spots, caudal fin dark.

Siganus virgatus (Valenciennes, 1835)

Chest in front of ventral fins scaly, body broad, 2 dark brown oblique grooves on the head and forebody, yellow between and behind grooves, bluish spots and stripes on

both grooves and border area.

Dagetichthys commersonnii (Lacepède, 1802)

Body elongated; the presence of pectoral fins; dorsal and anal fins fused with caudal fin; 70-83 dorsal-fin rays; 59-66 anal-fin rays; 12 caudal-fin rays; and dorsal and anal fins black, with margins white.

Population and ecological aspect of fish in Bengawan Solo River estuary

The total number of individuals (*N*) of each fish species varies (Figure 3). Furthermore, 615 fish samples were collected from the Bengawan Solo River estuary. The highest number of individuals was obtained from station 1 (219 individuals), followed by station 2 (202 individuals) and station 3 (194 individuals). At all stations, the Ariidae family consisting of *Arius maculatus* and *Hexanematichthys sagor* was recorded as the most dominant, with 104 and 136 individuals, respectively. The Ariidae family is a group of predatory fish that use the mangrove environment as a nursery and feeding ground, often found in lower rivers, estuaries, and intertidal areas. The family with the most species found at all stations was the Serranidae, with eight species, including *Epinephelus coioides*, *Epinephelus malabaricus*, *Epinephelus erythrurus*, *Epinephelus faveatus*, and *Epinephelus lancoelatus*. Serranidae fish habitat is at the bottom of the water and is mostly associated with coral reefs in shallow areas; some species live in rocky, sandy, and muddy estuaries.

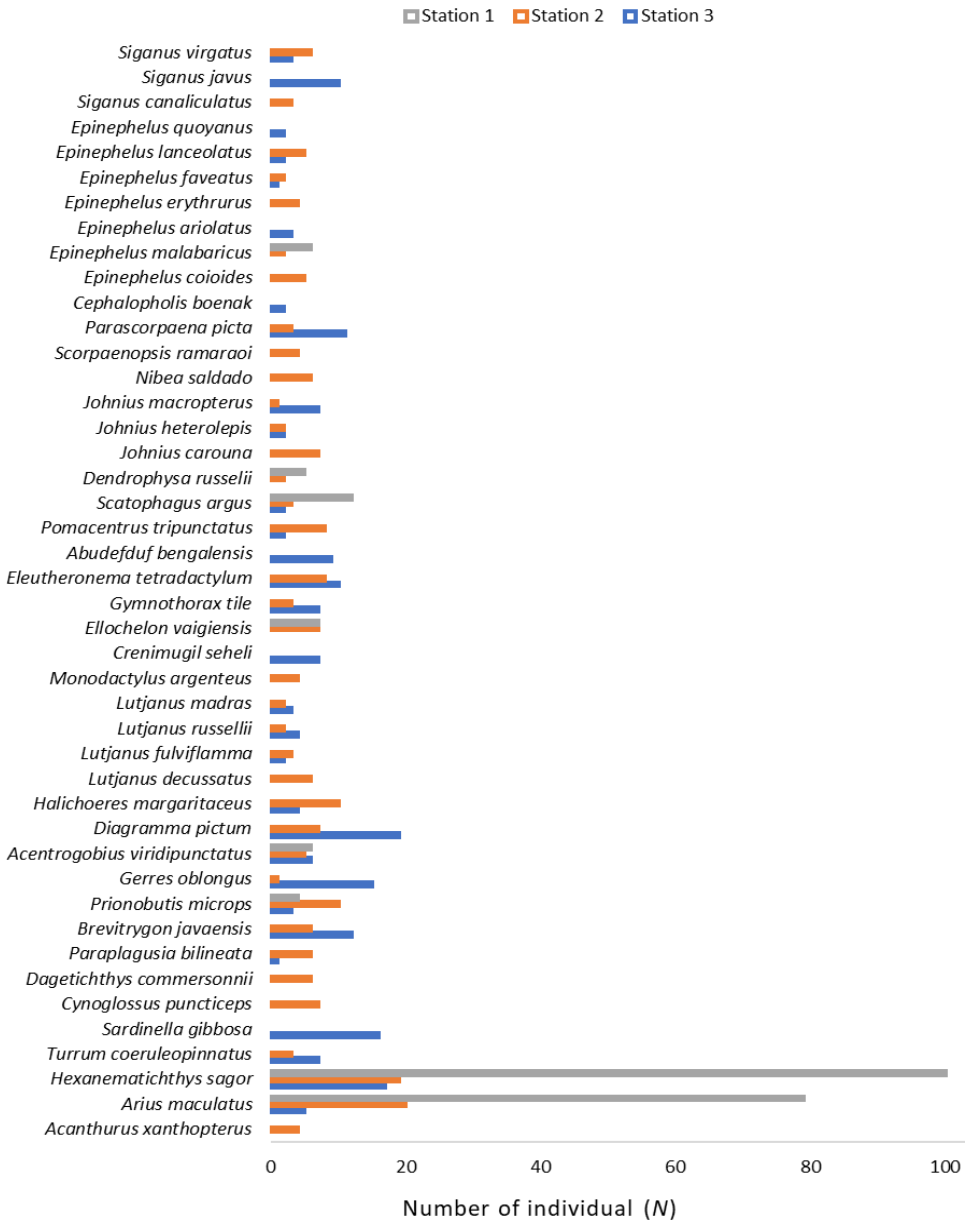

Figure 3. The number of specimens (*N*) of the fish assemblage during three months of sampling in the Bengawan Solo River estuary, Indonesia

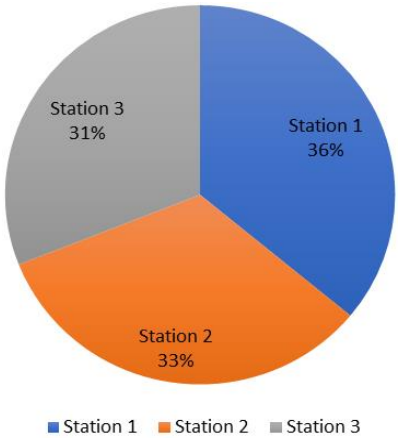

Figure 4. Percentage of the total fish species richness on the Bengawan Solo River estuary, Indonesia

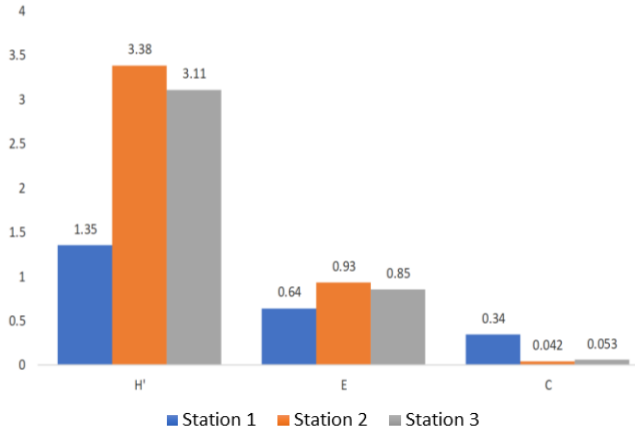

Figure 5. Index of Diversity (H'), Evenness (H), dominant index analysis (C) of fish species assemblage from Bengawan Solo River estuary, Indonesia

The percentage of the total number of fish obtained at the three research stations is shown in Figure 4. The highest percentage was at station 1, namely, 36% (218 individuals), followed by station 2, 33% (202 individuals), and the lowest was at station 3, namely 31% (194 individuals). Station 1, although it is close to shrimp ponds and settlements, the water currents are calmer, so many types of fish are available. At station 1, there were fewer species than at other stations, but the number of individuals was higher. At station 2, the number of species was higher than at other stations; because station 2 was a mangrove area with very high productivity, it became a hot spot for various fish species to congregate and breed. The waters around mangroves consistently receive nutrients from leaf litter which is then broken down by bacteria to become the nutritional sources for aquatic animals. Station 3 has the lowest number of individuals because station 3 is an intertidal zone that experiences sea tides, resulting in high fish mobility.

Fish have varied diversity at different times and locations. Species' existence affects the number of species, individuals, and families and the value of diversity, evenness or uniformity, and dominance at each station (Magurran 1988). The analysis results of the fish diversity index at the estuary of the Bengawan Solo River, Lamongan Regency, obtained 1.35-3.38 (Figure 4); these results include moderate to high variability. According to Magurran (1988), diversity is high when the diversity index value (H') is >3, medium 1<H'<3, and low if H'<1. The higher H' indicates, the higher the number of species. Shown at station 2 (near mangroves) has the highest number of species, namely 38 species with a diversity (H') of 3.38 or H'> 3 (high diversity). Following Krebs (1978), the value of diversity will increase if the number of species is more and the proportion of species is more evenly distributed. The existence of mangroves along watersheds is associated with the presence of fish; the higher the number of mangroves, the higher the number of fish (Yustina 2001). The lowest diversity is at station 1 with a value (H') 1.35 or 1<H'<3 (medium). Station 1 has lower diversity than other stations because it is close to shrimp ponds and settlements, so human activities change the natural function of the river. This study benefits future policies for the government to protect estuary ecosystems because many fish resources can still be used as a food source.

Based on the analysis of the uniformity index (E), the uniformity or evenness of fish in the Bengawan Solo River estuary was 0.64-0.93 (Figure 4). This figure is categorized as high uniformity (0.6≤E≤1). High uniformity indicates that the presence of fish in the area is evenly distributed, and no fish dominate (Krebs 1989; Hossain et al. 2012). Uniformity is inversely proportional to dominance; if uniformity is high, then dominance will be low. The analysis showed that the highest uniformity was at station 2, namely 0.93, while the lowest was at station 1, namely 0.64. This is supported by the condition of the aquatic environment, where station 2 is close to mangroves with high vegetation. In contrast, station 1 is close to settlements which can be affected by human activity (Rizwan et al. 2017).

Based on the dominance index analysis (C), the dominance of fish in the Bengawan Solo River estuary was in the range of 0.042-0.34 (Figure 5). This figure is categorized as low dominance (0<C<0.5). Low dominance indicates that in these waters, no fish dominate. The highest dominance was at station 1, namely 0.34, while the lowest was at station 2, namely 0.042. It is linear with the uniformity index. Therefore, the dominance index is inversely proportional to the uniformity index (Hossain et al. 2012; Rizwan et al. 2017).

In conclusion, 44 fish species grouped into 22 families have been recorded from the waters of the Bengawan Solo estuary, Lamongan Regency, East Java, Indonesia. The Ariidae family (*Arius maculatus*) and (*Hexanematichthys sagor*) are the most widely caught fish in the region. The diversity index (H') of the species assemblage in the study area ranged from 1.35-3.38 or was categorized as medium to high level of biodiversity, with an evenness index (E) 0.64-0.93 and a dominance index (C) 0.042-0.34. These

indexes indicate that in these waters evenness, the number of individuals of each species is high, and no species dominates. However, information regarding habitat use and ecological interactions is urgently needed to accurately determine the distribution and ecology in Javanese waters (Widodo et al. 2020; Ihwan et al. 2020; Saptadjaja et al. 2020, Hasan et al. 2021c; Hasan et al. 2021d; Hasan et al. 2021f; Valen et al. 2022c; Manangkalangi et al. 2022; Hasan et al. 2023). This can be completed through more expedition results, more collections, complimentary use of eDNA analysis, and research incorporating morphological and molecular data (Hasan et al. 2021g; Nurjirana et al. 2022; Valen et al. 2022b).

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