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Cover: Fish species recorded in the Gowthami-Godavari Estuary, Andhra Pradesh: *Lutjanus johnii* (top left), *Triacanthus biaculeatus* (top right), *Acentrogobius cyanomos*, *Elops machnata*, *Trypauchen vagina*, *Oxyurichthys microlepis*. © Paromita Ray.

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COMMUNICATION

An overview of the fish diversity and their threats in the Gowthami-Godavari Estuary in Andhra Pradesh, India

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Abstract: The fish diversity of different estuarine habitats of the Gowthami-Godavari River was studied from 2014 to 2017. We recorded 231 species of finfishes belonging to 27 orders, 81 families, and 167 genera. Perciformes was the most speciose order, followed by Carangiformes and Clupeiformes. Of the 231 species, one is an Endangered species (*Silonia childreni*), three are Vulnerable (*Tenualosa toli*, *Cirrhinus cirrhosis*, and *Wallago attu*), three are Near Threatened, and 11 are Data Deficient species. We also recorded five exotic species from the study area, of which *Oreochromis mossambicus* was the most dominant. The major threats, including potential impacts of river regulation and climate change on the estuarine habitats of Gowthami-Godavari, are also discussed.

Keywords: Coringa, dam, eastern coast, ichthyofauna, mangroves.

సారాంశం: 2014 నుండి 2017 మధ్య కాలంలో, గౌతమి-గోదావరి నదికి చెందిన వివిధ నదీముఖ ఆవాసాలలో ఉండే చేపల వైవిధ్యం మీద అధ్యయనం చేయబడింది. మా అధ్యయనంలో 231 ఫిన్‌ఫిష్ జాతులను నమోదు చేసాము, ఇవి 27 ఆర్డర్‌లు, 81 ఫామిలీస్ మరియు 167 జెనెరేలకు చెందినవి. నమోదు చెయ్యబడిన ఈ 231 ఫిన్‌ఫిష్‌లలో, అత్యధికంగా పెర్సిఫార్మ్స్ జాతులు ఉన్నాయి, వాటి తర్వాత కారంగిఫార్మ్స్ మరియు క్లూపీఫార్మ్స్ జాతులు ఉన్నాయి. ఈ 231 జాతులలో, ఒకటి అంతరించిపోతున్న జాతి (సిలోనియా చిల్డ్రని), మూడు వాల్నరబుల్ (టెనువాలోసా టోలి, సిర్రినస్ సిర్రోసిస్, మరియు వల్లగో అట్టు), మూడు ముప్పు వొంచి ఉన్నవి మరియు 11 డేటా లోపం ఉన్న జాతులు. మా అధ్యయనంలో ఐదు అన్యదేశ జాతులను కూడా నమోదు చేసాము, వాటిలో ఒరియోక్రోమిస్ మొసాంబికస్ ఎక్కువుగా కనిపించాయి. అంతే కాకుండా గౌతమి-గోదావరి నదీముఖ ఆవాసాలపై నియంత్రణ మరియు వాతావరణ మార్పుల గురించి కూడా మా అధ్యయనంలో చర్చించబడ్డాయి.

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Author contributions: PR—collection of field data, analysis, preparation of manuscript. GM—collection of field data and preparation of manuscript. JAJ—guidance on the study, manuscript reviewing and editing. KS—guidance on the study, manuscript editing and reviewing,

Acknowledgements: This study was part of a UNDP-GEF-MoEF&CC-APFD project, 'Establishment of Knowledge-based Management System in the East Godavari River Estuarine Ecosystem (EGREE Project)' of the Wildlife Institute of India. The authors would like to thank the director, and dean of the Wildlife Institute of India for providing their support in terms of infrastructure and guidance. The authors would also like to acknowledge the support of the Andhra Pradesh Forest Department, who provided us with the necessary permissions (Rc. No. 23833/2012/WL-S dated 29/11/2013) and support to carry out the study between 2013 and 2017. We are very grateful to Prasad Anna, Raju, and other local fishers of the East Godavari district, without whom this project would not have been possible. We thank Leela Prasad for helping us during some of the field surveys and Steve Lockett for his assistance in editing this manuscript.

INTRODUCTION

Among the large monsoonal rivers of the Indian peninsula, the Godavari River is the largest, with a drainage basin of 312,812 km^2 (Rao et al. 2015). The river originates at Triambakeshwar in the Western Ghats and travels eastward for ~1,460 km flowing through eight states and various landscapes such as the Western Ghats, Deccan traps of central India, and the Eastern Ghats along the eastern coast. It finally drains into the Bay of Bengal through a number of distributaries before creating a large, fertile delta in Andhra Pradesh. The Godavari river basin accounts for nearly 10% of India's geographical area, thereby playing a major role in accruing socio-ecological, economic, and cultural benefits to the country.

At its confluence with Bay of Bengal, numerous distributaries of the Godavari River form an estuarine complex constituting a diverse array of coastal habitats that include the estuaries formed at the river mouths, mangrove forests, and a large bay partially enclosed by a natural sand spit known as Hope Island. The mangroves created at the confluence of Gowthami River, a major distributary of the Godavari River, are among the largest mangrove forests in India. These habitats support rich and unique biodiversity, including rare mangrove species such as *Ceriops decandra* and *Xylocarpus granatum*, and threatened mammals such as the Fishing Cat *Prionailurus viverrinus* and Smooth-coated Otter *Lutrogale perspicillata* (Malla 2014; Malla et al. 2019). The estuarine complex and the mangrove-lined creeks of the estuary located at the interface of freshwater and salt water also contributes immensely to the region's fisheries particularly supporting the sustenance of the local small-scale fisheries.

Many studies, including those by Krishnamurthy & Jeyaseelan (1981), Mukherjee et al. (2013), Ramachandra et al. (2013), and Ramanujam et al. (2014), have documented the diversity of fish fauna present in Indian estuaries. In the case of the lower basin of the Godavari River, earlier ichthyological studies provide substantial information on the distribution and taxonomy of fish species (Day 1888; Chacko & Ganapati 1949; Rao 1965, 1976; Rajyalakshmi 1973; Rao 1976; Talwar & Jhingran 1991). Species including *Awaous fluviatilis* Rao, 1971 and *Incara multisquamatus* Rao, 1961 were first described from the Godavari delta. Nearly two decades ago, Krishnan & Mishra (2001) provided a comprehensive summary of the fish diversity of the Godavari River estuary, accounting for 312 species belonging to 189 genera and 88 families.

In this paper, we provide an overview of the fish diversity and distribution in different habitats of the Godavari River estuarine complex, and specifically focusing on the fish diversity in the mangrove-lined creeks. We also discuss various threats to these mangrove forests, and their fish communities. This study is important in the context of the vulnerability of this estuary, and its biological communities to potential large-scale changes triggered by rising sea levels and freshwater regulation by an under-construction large dam.

METHODS

Study area

This study was conducted in the Godavari River Estuary located in the southeastern state of Andhra Pradesh in peninsular India. Before its confluence with the sea, the river branches out into two major distributaries, namely the Gowthami-Godavari and Vasistha-Godavari. The present study focuses on the Gowthami distributary of the river (16.98 °N, 82.30 °E and 16.58 °N, 82.31 °E).

With an area of 316 km^2, a substantial part of the mangroves formed at the northern confluence of Gowthami-Godavari with the sea are protected inside the Coringa Wildlife Sanctuary (CWS) (Bagaria et al. 2021). Here, the mangroves are drained by three major sub-tidal creeks, namely Thulyabhaga, Coringa, and Gaderu; these creeks flow south to north, dividing the sanctuary into different zones. Another smaller sub-tidal creek, namely Giriyampeta is located outside the southern border of the sanctuary. In addition to these major creeks, the sanctuary is drained by several smaller sub-tidal and intertidal creeks.

The subtidal creeks drain into the Kakinada Bay, a naturally formed semi-enclosed bay formed at the northern edge of the sanctuary. The main branch of the Gowthami-Godavari creates a riverine estuary at the southern edge of the sanctuary, where the tidal influence can extend up to 50 km upstream.

Sampling sites

Fish sampling was carried out across 52 sites between 2014 and 2017 (Figure 1). Of these, 28 sites were located within mangrove creeks of the CWS (Image 1), 16 sites were in the riverine part of the estuary, and eight sites were located in the Kakinada Bay. Additional surveys were carried out in the local fish markets and landing centers located adjacent to the mangroves, and the river

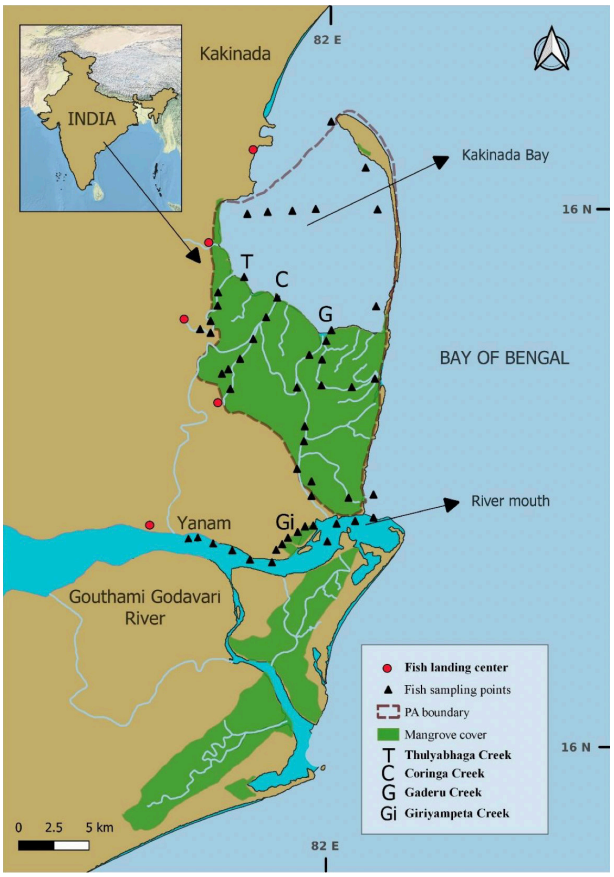

Figure 1. Map showing the location of Coringa Wildlife Sanctuary along with all the fish sampling sites, including landing centers in East Godavari district, Andhra Pradesh.

Image 1. One of the sampling sites during spring high tide. This site was located within the mangrove creeks surveyed inside the Coringa Wildlife Sanctuary, Andhra Pradesh. © Giridhar Malla.

Image 2. An aquaculture pond adjoining the mangrove forests of the Coringa Wildlife Sanctuary, Andhra Pradesh. © Paromita Ray.

Image 3. Intrusion of sand into the mangrove forests noticed on the seaward side of the Coringa Wildlife Sanctuary, Andhra Pradesh. © Giridhar Malla.

mouth.

In the main river within the sanctuary, fishes were collected using locally available trammel nets and gill nets, which were set perpendicular to the water flow for a period of one hour during low tides. In the case of intertidal creeks, block nets were placed at the creek entrance at the beginning of low tide. The fishes that remained within the blocked creek were collected before the onset of the next high tide. Since sampling was conducted inside a protected area, only unidentified specimens were collected for further identification in the laboratory. On a few occasions, specimens were collected opportunistically from fishers' catches from the subtidal creeks, bay, or the river mouth.

Identifications were made using the FAO Fish Catalogue (Fischer & Whitehead 1974; Fischer & Bianchi 1984) and other taxonomic keys available for the region (Day 1888; Jayaram 2010). The correct taxonomy of the species was updated in accordance with the California Academy of Sciences' online repository, the Catalog of Fishes (Fricke et al. 2021). The functional guilds and migratory behavior of the species were confirmed following FishBase (Froese & Pauly 2021) while the threatened status of each of the species followed the latest IUCN Red List of Threatened Species (IUCN 2021).

RESULTS AND DISCUSSION

Diversity and distribution of fishes in the estuary

In the present study, total of 231 species of finfish belonging to 27 orders, 81 families, and 167 genera were recorded (Table 1; Images 4–7). Order Perciformes was the most speciose with 41 species, 22 genera, and 10 families. It was followed by Carangiformes (30 species, 29 genera, and 12 families), and Clupeiformes (25 species, 16 genera, and five families). Among the families (Figure 2), Carangidae was represented by the highest number of species (16 species), followed by Gobiidae and Sciaenidae (both represented by 12 species each). Of all the recorded species, 179 were carnivorous, 45 were omnivorous and two were herbivorous.

In comparison to the earlier study carried out by Krishnan & Mishra (2001), fewer finfish species were recorded during this study. This difference may not necessarily suggest a decline in the overall number of species in the estuary, but is more reflective of the taxonomic and nomenclatural changes. As an example, Krishnan & Mishra (2001) reported seven species of *Stolephorus* from this estuary: *S. andhraensis, S. baganensis, S. commersonii, S. dubiosus, S. indicus, S. insularis*, and *S. waitei*. However, Hata et al. (2020, 2021) made several revisions to the genus *Stolephorus* including updating the species' distribution records. The authors suggested the non-occurrence of *S. baganensis*, *S. commersonii* and *S. waitei* in India, thus making the records of these three species in the Godavari estuary questionable.

On the other hand, species including *Plectorhinchus gibbosus*, *Diagramma pictum,* and non-native species such as *Oreochromis mossambicus* and *Piaractus brachypomus* were recorded for the first time from this estuary. Moreover, the study by Krishnan & Mishra (2001) had a broader scope, having included other distributaries of Godavari River, in comparison to the current study whose focus was the Gowthami-Godavari system. Likewise, the number of species recorded in this study is relatively lower than other large estuaries or mangrove forests located on the east coast of India, including the Sundarbans mangroves (Bhattacharya et al. 2018) and Chilika Lake (Mohanty et al. 2015), from where 312 and 299 species have been recorded, respectively.

Many of the species recorded during this study have also been recorded from other Indian estuaries (Bijukumar & Sushama 2000; Ghosh et al. 2011; Mohanty et al. 2015; Bhattacharya et al. 2018; Sreekanth et al. 2020; Roshni et al. 2021). A number of freshwater species belonging to orders Cypriniformes and Siluriformes were recorded from the mangrove creeks. While a few of them, such as *Mystus gulio* and *Etroplus suratensis* (Image 7a) are known to occur in brackish water habitats (Bijukumar & Sushama 2000), the occurrence of carp species including *Labeo rohita, L. calbasu*, and *L. fimbriatus* were recorded in a few creeks during the post-monsoon season. This is the time when the mangrove forest gets flushed annually with sediment-laden fresh water from the river. The occurrence of these freshwater fishes in the mangrove creeks, however, may also be explained by the stocking of these species in aquaculture ponds abutting the mangroves, creeks, and canals across the East Godavari district. The number of species recorded from the mangrove-lined creeks (150 species), river mouth (151 species), and the Kakinada Bay (149 species) was similar. Nearly 67% of the total species occurred in at least two habitat types showing a high degree of overlap between the estuarine habitats of the delta. Of these, 64 species were found in all three habitat types. The high degree of overlap in species between the habitats indicates the importance of connectivity within this estuarine complex. Fishes recorded exclusively from the bay and the river mouth respectively, constituted nearly 16% and 11% of the total number of species recorded during this study.

Connectivity between the three estuarine habitats and the seascape of East Godavari district is crucial for migratory species occurring in the estuary. The flagship migratory species is *Tenualosa ilisha*, which undertakes large-scale migration from the sea into the Godavari River during the monsoon, when they contribute to important fisheries. It is popularly known as 'Pulasa' in Andhra Pradesh (or 'Hilsa' throughout the Indian sub-continent) and has high commercial value. Other important migratory species occurring in the estuary include *Tenualosa toli*, *Anodontostoma chacunda*, *Lates calcarifer* (Image 4a), and many eel species. Other species, such as mullets (Mugilidae), undertake migrations in the creeks on shorter temporal scales, mainly driven by the tidal regimes and food availability.

Threatened and exotic species

Four species recorded from this estuarine complex are assessed as threatened on the IUCN Red List. These include the Endangered *Silonia childreni,* and the Vulnerable *Tenualosa toli, Cirrhinus cirrhosus* and *Wallago attu*. The Godavari River is an important habitat for *Silonia childreni*, a highly threatened catfish species occurring in the large river systems of peninsular India. On

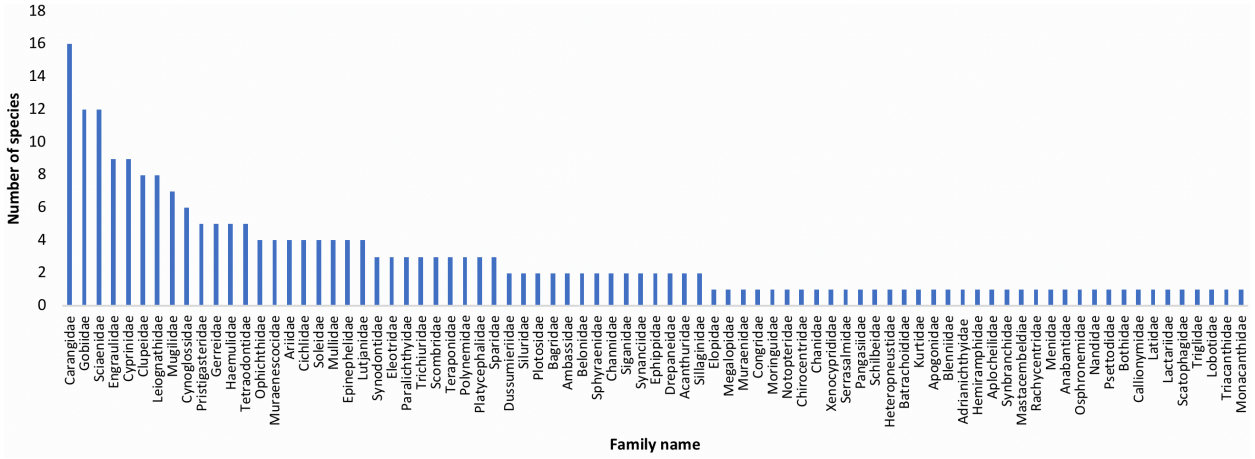

Figure 2. Family-wise number of species recorded in this study.

multiple occasions, the authors recorded its distribution from various parts of the river stretch in Andhra Pradesh, including the estuarine part of the river. Despite this, catches of this large catfish species has been declining, as observed by the local fishers. Additionally, three Near Threatened species: *Ompok bimaculatus, Harpadon nehereus*, & *Protonibea diacanthus* and 10 Data Deficient species: *Platycephalus indicus*, *Epinephelus tauvina*, *Acanthopagrus datnia*, *Rastrelliger kanagurta*, *Scomberomorus guttatus*, *Parapocryptes rictuosus*, *Taenioides cirratus*, *Psettodes erumei*, *Cynoglossus arel*, & *Megalops cyprinoides* were recorded during this study (Table 2). Of the 10 Data Deficient species, *P. indicus* was among the more commonly occurring species in the estuary, which was recorded from all the three habitat types during this study. The two eel species, *Parapocryptes rictuosus* and *Taenioides cirratus*, were recorded only on one occasion in a fisher's catch from the mangrove creek of Tulyabagha inside the CWS.

Five exotic species were also recorded during this study. These include *Oreochromis mossambicus, O. niloticus, Ctenopharyngodon idella, Cyprinus carpio*, and *Piaractus brachypomus*. The first four species are recognized as worst invasive species' of the world by the IUCN Global Invasive Species Database (2021) due to their negative impacts on native fauna. Alarmingly, *O. mossambicus* was found to be among the most dominant species in the CWS. This species appeared to have established a self-sustaining wild population within the Thulyabagha and Coringa creeks of the sanctuary, where the salinities annually ranged from 2 ppt to 20 ppt. The remaining exotic species were recorded only from the riverine zone of the estuary complex.

The main pathway of exotic fish introduction is likely to be through the aquaculture ponds that stock these exotic species. *Piaractus brachypomus* (Pirapitinga), a native of South America, was first recorded from the fish landing centre by the authors in 2013. Since then, this species has become a popular fish in the region (and across the country) and is being extensively stocked in aquaculture ponds along the river, mangrove creeks and canals. It is commonly sold in the local fish markets under the guise of 'white pomfret' or 'freshwater pomfret' and is even being recorded in the catches made by the local fishers in the river (Paromita Ray and Giridhar Malla pers. obs.). This could indicate its possible escape from the aquaculture farms into, and possible establishment within, the river. The authors also noted two occurrence records of *Pterygoplichthys* sp. (family Loricariidae) from the freshwater upstream zone of the river in the East Godavari district. Local fishers recorded this species during the flood season.

Major threats

The Godavari River delta and the estuarine complex have been greatly altered by human activities. The Godavari River delta, along with the Krishna River delta to its south, constitutes one of the largest offshore natural gas reserves in India. The Kakinada Bay also acts as a natural harbour as well as an important port for the state. Additionally, the industrial city of Kakinada (also the headquarters of the East Godavari district) is located adjacent to the mangroves and the estuary. Some of the main causes for degradation of the estuarine ecosystems and the mangrove forests include: diversion for aquaculture, agriculture, salt pans and industries; and rapid and unplanned urbanization (Jayanthi et al. 2018; Bagaria et al. 2021). Other threats include discharge of untreated effluents from anthropogenic sources such as aquaculture farms and industries into the river, canals

Table 1. Habitat-wise list of finfish species recorded during this study from the Godavari River estuary complex.

	Order	Family	Species	Main River	Mangroves	Kakinada Bay
1	Elopiformes	Elopidae	*Elops machnata* (Fabricius, 1775) (Image 5e)	0	1	0
2		Megalopidae	*Megalops cyprinoides* (Broussonet, 1782)	1	1	1
3	Anguilliformes	Muraenidae	*Strophidon sathete* (Hamilton, 1822)	1	1	0
4		Ophichthidae	*Bascanichthys deraniyagalai* Menon, 1961	1	1	1
5			*Cirrhimuraena playfairii* (Günther, 1870)	1	1	0
6			*Pisodonophis boro* (Hamilton, 1822)	1	1	0
7			*Pisodonophis cancrivorus* (Richardson, 1848)	1	1	0
8		Muraenescocidae	*Congresox talabonoides* (Bleeker, 1852)	1	1	0
9			*Congresox talabon* (Cuvier, 1829)	1	1	0
10			*Muraenesox cinereus* (Forsskål, 1775)	1	1	0
11			*Muraenesox bagio* (Hamilton, 1822)	1	1	0
12		Congridae	*Uroconger lepturus* (Richardson, 1845)	1	0	0
13		Moringuidae	*Moringua raitaborua* (Hamilton, 1822)	1	1	1
14	Osteoglossiformes	Notopteridae	*Notopterus notopterus* (Pallas, 1769)	1	0	0
15	Clupeiformes	Clupeidae	*Anodontostoma chacunda* (Hamilton, 1822)	1	1	0
16			*Escualosa thoracata* (Valenciennes, 1847)	1	1	1
17			*Hilsa kelee* (Cuvier, 1829)	1	1	1
18			*Nematalosa nasus* (Bloch, 1795)	1	0	0
19			*Sardinella longiceps* Valenciennes, 1847	1	1	1
20			*Sardinella fimbriata* (Valenciennes, 1847)	1	1	1
21			*Tenualosa ilisha* (Hamilton, 1822)	1	0	0
22			*Tenualosa toli* (Valenciennes, 1847)	1	1	0
23		Dussumieriidae	*Dussumieria acuta* Valenciennes, 1847	0	1	1
24			*Dussumieria elopsoides* Bleeker, 1849	0	1	1
25		Engraulidae	*Coilia dussumieri* Valenciennes, 1848	1	1	1
26			*Coilia reynaldi* Valenciennes, 1848	1	1	1
27			*Setipinna taty* (Valenciennes, 1848)	1	1	1
28			*Setipinna tenuifilis (*Valenciennes, 1848)	1	1	1
29			*Stolephorus commersonnii* Lacepède, 1803	1	1	1
30			*Stolephorus indicus* (van Hasselt, 1823)	0	0	1
31			*Thryssa mystax* (Bloch & Schneider, 1801)	1	1	1
32			*Thryssa malabarica* (Bloch, 1795)	1	1	1
33			*Thryssa baelama* (Fabricius, 1775)	1	1	1
34		Chirocentridae	*Chirocentrus dorab* (Fabricius, 1775)	1	0	1
35		Pristigasteridae	*Ilisha melastoma* (Bloch & Schneider, 1801)	1	1	1
36			*Ilisha megaloptera* (Swainson, 1838)	1	1	1
37			*Opisthopterus tardoore* (Cuvier, 1829) (Image 4c)	1	1	1
38			*Pellona ditchela* Valenciennes, 1847	1	1	1
39			*Raconda russeliana* Gray, 1831	1	0	1
40	Gonorynchiformes	Chanidae	*Chanos chanos* (Fabricius, 1775)	1	0	1
41	Cypriniformes	Cyprinidae	*Cirrhinus cirrhosus* (Bloch, 1795)	1	1	0
42			*Cirrhinus mrigala* (Hamilton, 1822)	1	0	0
43			*Cyprinus carpio* Linnaeus, 1758	1	0	0

	Order	Family	Species	Main River	Mangroves	Kakinada Bay
44			*Labeo catla* (Hamilton, 1822)	1	0	0
45			*Labeo calbasu* (Hamilton, 1822)	1	1	0
46			*Labeo fimbriatus* (Bloch, 1795)	1	1	0
47			*Labeo rohita* (Hamilton, 1822)	1	1	0
48			*Puntius sophore* (Hamilton, 1822)	1	1	0
49			*Pethia ticto* (Hamilton, 1822)	1	0	0
50		Xenocyprididae	*Ctenopharyngodon idella* (Valenciennes, 1844)	1	0	0
51	Characiformes	Serrasalmidae	*Piaractus brachypomus* (Cuvier, 1818)	1	0	0
52	Siluriformes	Plotosidae	*Plotosus canius* Hamilton, 1822	1	1	0
53			*Plotosus lineatus* (Thunberg, 1787)	0	0	1
54		Ailiidae	*Silonia childreni* (Sykes, 1839)	1	0	0
55		Bagridae	*Mystus gulio* (Hamilton, 1822)	1	1	0
56			*Mystus vittatus* (Bloch, 1794)	1	1	0
57		Pangasiidae	*Pangasius pangasius* (Hamilton, 1822)	1	1	0
58		Siluridae	*Wallago attu* (Bloch & Schneider, 1801)	1	0	0
59			*Ompok bimaculatus* (Bloch, 1794)	1	0	0
60		Heteropneustidae	*Heteropneustes fossilis* (Bloch, 1794)	1	1	0
61		Ariidae	*Arius arius* (Hamilton, 1822)	1	1	1
62			*Arius gagora* (Hamilton 1822)	1	1	1
63			*Arius maculatus* (Thunberg, 1792)	1	1	1
64			*Plicofollis dussumieri* (Valenciennes, 1840)	0	0	1
65	Aulopiformes	Synodontidae	*Saurida tumbil* (Bloch, 1795)	0	0	1
66			*Synodus indicus* (Day, 1873)	0	0	1
67			*Harpadon nehereus* (Hamilton, 1822)	1	1	1
68	Batrachoidiformes	Batrachoididae	*Allenbatrachus grunniens* (Linnaeus, 1758) (Image 7c)	1	1	0
69	Scombriformes	Scombridae	*Katsuwonus pelamis* (Linnaeus, 1758)	0	0	1
70			*Rastrelliger kanagurta* (Cuvier, 1816)	1	0	1
71			*Scomberomorus guttatus* (Bloch & Schneider, 1801)	0	0	1
72		Trichiuridae	*Eupleurogrammus muticus* (Gray, 1831)	1	1	0
73			*Lepturacanthus savala* (Cuvier, 1829)	1	0	1
74			*Trichiurus lepturus* Linnaeus, 1758	1	0	1
75	Syngnathiformes	Mullidae	*Upeneus sulphureus* Cuvier, 1829	1	1	1
76			*Upeneus vittatus* (Forsskål, 1775)	1	0	0
77			*Upeneus moluccensis* (Bleeker, 1855)	0	0	1
78			*Upeneus taeniopterus* Cuvier, 1829	1	1	1
79		Callionymidae	*Callionymus carebares* Alcock, 1890	0	1	0
80	Kurtiformes	Kurtidae	*Kurtus indicus* Bloch, 1786 (Image 7d)	0	1	1
81		Apogonidae	*Jaydia queketti* (Gilchrist 1903) (Image 6d)	0	0	1
82	Gobiiformes	Eleotridae	*Eleotris fusca* (Bloch & Schneider, 1801)	1	1	0
83			*Butis butis* (Hamilton, 1822) (Image 5d)	0	1	0
84			*Butis humeralis* (Valenciennes, 1837)	0	1	0
85		Gobiidae	*Aulopareia cyanomos* (Bleeker, 1849) (Image 5b)	0	1	1
86			*Apocryptes bato* (Hamilton, 1822)	0	1	0
87			*Boleophthalmus boddarti* (Pallas, 1770)	0	1	1

	Order	Family	Species	Main River	Mangroves	Kakinada Bay
88			*Glossogobius giuris* (Hamilton, 1822)	1	1	0
89			*Oxyurichthys microlepis* (Bleeker, 1849) (Image 7b)	0	1	0
90			*Parapocryptes rictuosus* (Valenciennes, 1837)	0	1	0
91			*Periophthalmus chrysospilos* Bleeker, 1853	0	1	0
92			*Taenioides anguillaris* (Linnaeus, 1758)	1	1	0
93			*Taenioides cirratus* (Blyth, 1860)	1	1	0
94			*Trypauchen vagina* (Bloch & Schneider, 1801) (Image 6e)	1	1	0
95			*Yongeichthys nebulosus* (Forsskål, 1775)	1	0	0
96			*Stigmatogobius sadanundio* (Hamilton, 1822)	1	0	0
97	Synbranchiformes	Mastacembelidae	*Macrognathus pancalus* Hamilton 1822	1	0	0
98		Synbranchidae	*Ophisternon bengalense* McClelland, 1844	1	0	0
99	Anabantiformes	Anabantidae	*Anabas testudineus* (Bloch, 1792)	1	1	0
100		Osphronemidae	*Trichogaster fasciata* Bloch & Schneider, 1801	1	0	0
101		Channidae	*Channa punctata* (Bloch, 1793)	1	0	0
102			*Channa striata* (Bloch, 1793)	1	0	0
103		Nandidae	*Nandus nandus* (Hamilton, 1822)	0	1	0
104	Carangiformes	Latidae	*Lates calcarifer* (Bloch, 1790) (Image 4a)	1	1	0
105		Lactariidae	*Lactarius lactarius* (Bloch & Schneider, 1801)	1	0	1
106		Sphyraenidae	*Sphyraena obtusata* Cuvier, 1829	0	0	1
107			*Sphyraena jello* Cuvier, 1829	0	0	1
108		Polynemidae	*Eleutheronema tetradactylum* (Shaw, 1804)	1	1	1
109			*Polydactylus sextarius* (Bloch & Schneider, 1801)	1	1	1
110			*Leptomelanosoma indicum* (Shaw, 1804)	1	1	1
111		Psettodidae	*Psettodes erumei* (Bloch & Schneider, 1801)	1	0	1
112		Bothidae	*Bothus myriaster* (Temminck & Schlegel, 1846)	0	1	1
113		Paralichthyidae	*Pseudorhombus arsius* (Hamilton, 1822)	0	1	1
114			*Pseudorhombus triocellatus* (Bloch & Schneider, 1801)	0	1	1
115			*Pseudorhombus elevatus* Ogilby, 1912	1	1	1
116		Soleidae	*Aesopia cornuta* Kaup, 1858	0	0	1
117			*Solea ovata* Richardson, 1846	0	1	1
118			*Dagetichthys albomaculatus* (Kaup, 1858)	1	1	1
119			*Zebrias synapturoides* (Jenkins, 1910)	1	1	1
120		Cynoglossidae	*Cynoglossus arel* (Bloch & Schneider, 1801)	1	1	1
121			*Cynoglossus bilineatus* (Lacepède, 1802)	1	1	1
122			*Cynoglossus puncticeps* (Richardson, 1846)	1	1	1
123			*Cynoglossus lingua* Hamilton, 1822	1	1	0
124			*Cynoglossus cynoglossus* (Hamilton, 1822)	1	1	1
125			*Paraplagusia bilineata* (Bloch, 1787)	1	1	1
126		Menidae	*Mene maculata* (Bloch & Schneider, 1801)	0	1	0
127		Carangidae	*Megalaspis cordyla* (Linnaeus, 1758)	0	0	1
128			*Scyris indica* (Rüppell, 1830)	1	0	1
129			*Alepes djedaba* (Fabricius, 1775)	1	0	1
130			*Alepes kleinii* (Bloch, 1793)	1	0	1
131			*Atropus atropos* (Bloch & Schneider, 1801)	0	0	1

	Order	Family	Species	Main River	Mangroves	Kakinada Bay
132			*Atule mate* (Cuvier, 1833)	1	0	1
133			*Platycaranx malabaricus* (Bloch & Schneider, 1801)	0	0	1
134			*Caranx ignobilis* (Forsskål, 1775)	0	1	1
135			*Caranx sexfasciatus* Quoy & Gaimard, 1825	0	1	1
136			*Caranx heberi* (Bennett, 1830)	0	0	1
137			*Decapterus russelli* (Rüppell, 1830)	0	0	1
138			*Parastromateus niger* (Bloch, 1795)	0	1	1
139			*Scomberoides commersonnianus* Lacepède, 1801	0	0	1
140			*Scomberoides tol* (Cuvier, 1832)	0	0	1
141			*Selar crumenophthalmus* (Bloch, 1793)	0	0	1
142			*Trachinotus mookalee* Cuvier, 1832. (Image 6a)	0	1	1
143		Rachycentridae	*Rachycentron canadum* (Linnaeus, 1766)	0	0	1
144	Cichliformes	Ambassidae	*Ambassis gymnocephalus* (Lacepède, 1802)	1	1	0
145			*Chanda nama* Hamilton, 1822	1	1	0
146		Cichlidae	*Etroplus suratensis* (Bloch, 1790) (Image 7a)	1	1	0
147			*Pseudetroplus maculatus* (Bloch, 1795)	1	0	0
148			*Oreochromis mossambicus* (Peters, 1852)	1	1	0
149			*Oreochromis niloticus* (Linnaeus, 1758)	1	0	0
150	Cyprinodontiformes	Aplocheilidae	*Aplocheilus blockii* Arnold, 1911	1	1	0
151	Beloniformes	Belonidae	*Strongylura strongylura* (van Hasselt, 1823)	1	0	1
152			*Xenentodon cancila* (Hamilton, 1822)	1	1	0
153		Hemiramphidae	*Hyporhamphus limbatus* (Valenciennes, 1847)	1	1	1
154		Adrianichthyidae	*Oryzias dancena* (Hamilton 1822)	0	1	0
155	Mugiliformes	Mugilidae	*Mugil cephalus* Linnaeus, 1758	1	1	1
156			*Chelon parsia* (Hamilton, 1822)	1	1	1
157			*Planiliza subviridis* (Valenciennes, 1836)	1	1	1
158			*Planiliza planiceps* (Valenciennes, 1836)	1	0	0
159			*Planiliza tade* (Fabricius, 1775)	1	1	0
160			*Rhinomugil corsula* (Hamilton, 1822)	1	1	0
161			*Crenimugil seheli* (Fabricius, 1775)	1	1	1
162	Blenniiformes	Blenniidae	*Omobranchus ferox* (Herre, 1927)	1	1	0
163	Perciformes *sedis mutabilis*	Sillaginidae	*Sillaginopsis domina* (Cuvier, 1816)	0	0	1
164			*Sillago sihama* (Fabricius, 1775)	1	1	1
165		Lutjanidae	*Lutjanus johnii* (Bloch, 1792) (Image 4b)	1	1	1
166			*Lutjanus russellii* (Bleeker, 1849)	0	1	1
167			*Lutjanus argentimaculatus* (Forsskål, 1775) (Image 5c)	0	1	1
168			*Lutjanus fulviflamma* (Forsskål, 1775)	0	1	1
169		Gerreidae	*Gerres filamentosus* Cuvier, 1829	1	1	1
170			*Gerres limbatus* Cuvier, 1830	1	1	1
171			*Gerres setifer* (Hamilton, 1822)	1	1	1
172			*Gerres oyena* (Fabricius, 1775)	1	1	1
173			*Gerres longirostris* (Lacepède, 1801)	0	0	1
174		Haemulidae	*Pomadasys kaakan* (Cuvier, 1830)	1	1	1

	Order	Family	Species	Main River	Mangroves	Kakinada Bay
175			*Pomadasys argenteus* (Forsskål, 1775)	1	1	1
176			*Pomadasys maculatus* (Bloch, 1793)	1	1	1
177			*Plectorhinchus gibbosus* (Lacepède, 1802)	0	0	1
178			*Diagramma pictum* (Thunberg, 1792)	0	0	1
179		Sparidae	*Acanthopagrus berda* (Fabricius, 1775)	0	0	1
180			*Acanthopagrus datnia* (Hamilton, 1822)	0	0	1
181			*Rhabdosargus sarba* (Gmelin, 1789)	0	0	1
182		Sciaenidae	*Chrysochir aurea* (Richardson, 1846)	0	1	1
183			*Daysciaena albida* (Cuvier, 1830)	0	1	1
184			*Dendrophysa russelii* (Cuvier, 1829)	1	1	1
185			*Johnius belangerii* (Cuvier, 1830)	0	1	1
186			*Johnius coitor* (Hamilton, 1822)	1	1	1
187			*Johnius dussumieri* (Cuvier, 1830)	0	1	1
188			*Kathala axillaris* (Cuvier, 1830)	0	1	1
189			*Nibea maculata* (Bloch & Schneider, 1801)	0	1	1
190			*Nibea soldado* (Lacepède, 1802)	0	1	1
191			*Otolithes ruber* (Bloch & Schneider, 1801)	1	1	0
192			*Panna microdon* (Bleeker, 1849)	0	1	1
193			*Protonibea diacanthus* (Lacepède, 1802)	0	1	1
194	Perciformes	Epinephelidae	*Epinephelus coioides* (Hamilton, 1822)	0	1	1
195			*Epinephelus malabaricus* (Bloch & Schneider, 1801)	0	1	1
196			*Epinephelus melanostigma* Schultz, 1953	0	0	1
197			*Epinephelus tauvina* (Fabricius, 1775)	0	0	1
198		Platycephalidae	*Grammoplites scaber* (Linnaeus, 1758)	1	1	0
199			*Cociella crocodilus* (Cuvier, 1829)	1	0	0
200			*Platycephalus indicus* (Linnaeus, 1758)	1	1	1
201		Triglidae	Lepidotrigla sp.	0	0	1
202		Synanceiidae	*Minous monodactylus* (Bloch & Schneider, 1801) (Image 4f)	0	1	1
203			*Minous inermis* Alcock 1889	0	0	1
204	Centrarchiformes	Terapontidae	*Terapon jarbua* (Fabricius, 1775) (Image 6c)	1	1	0
205			*Terapon puta* Cuvier, 1829	1	1	0
206			*Pelates quadrilineatus* (Bloch, 1790)	1	0	1
207	Acanthuriformes	Lobotidae	*Lobotes surinamensis* (Bloch, 1790)	1	0	1
208		Drepaneidae	*Drepane longimana* (Bloch & Schneider, 1801)	1	1	0
209			*Drepane punctata* (Linnaeus, 1758)	0	1	0
210		Ephippidae	*Ephippus orbis* (Bloch, 1787)	0	0	1
211			Platax sp.	0	0	1
212		Leiognathidae	*Leiognathus equula* (Forsskål, 1775)	1	1	1
213			*Eubleekeria splendens* (Cuvier, 1829)	1	1	1
214			*Leiognathus berbis* (Valenciennes, 1835)	0	1	1
215			*Photopectoralis bindus* (Valenciennes, 1835)	1	1	1
216			*Gazza minuta* (Bloch, 1795)	0	0	1
217			*Deveximentum insidiator* (Bloch, 1787)	1	1	1
218			*Nuchequula blochii* (Valenciennes, 1835)	0	1	1

	Order	Family	Species	Main River	Mangroves	Kakinada Bay
219			*Leiognathus ruconius* (Hamilton, 1822) (Image 4d)	1	1	1
220		Scatophagidae	*Scatophagus argus* (Linnaeus, 1766)	1	1	1
221		Siganidae	*Siganus canaliculatus* (Park, 1797)	1	1	1
222			*Siganus javus* (Linnaeus, 1766) (Image 4e)	1	1	1
223		Acanthuridae	*Acanthurus mata* (Cuvier, 1829) (Image 5a)	1	0	0
224			*Acanthurus xanthopterus* Valenciennes, 1835	1	1	1
225	Tetraodontiformes	Triacanthidae	*Triacanthus biaculeatus* (Bloch, 1786) (Image 6b)	0	0	1
226		Tetraodontidae	*Takifugu oblongus* (Bloch, 1786)	0	0	1
227			*Chelonodontops patoca* (Hamilton, 1822)	1	1	1
228			*Dichotomyctere fluviatilis* (Hamilton, 1822)	1	1	1
229			*Lagocephalus lunaris* (Bloch & Schneider, 1801)	1	0	1
230			*Lagocephalus inermis* (Temminck & Schlegel, 1850)	1	0	1
231		Monacanthidae	*Aluterus monoceros* (Linnaeus, 1758)	0	0	1
			Total	**151**	**150**	**149**

1—Presence recorded | 0—Presence not recorded.

Image 4. Images of fish species recorded in this study along with their standard lengths whenever available: a—*Lates calcarifer* | b—*Lutjanus johnii* (137 mm) | c—*Opisthopterus tardoore* (98 mm) | d—*Leiognathus ruconius* (48 mm) | e—*Siganus javus* (78 mm) | f—*Minous monodactylus* (72 mm). © Paromita Ray.

and the mangrove creeks (Rao et al. 2018); sand mining at the river bed, dredging of the creeks and river mouth (Malini & Rao 2004) alteration of the natural flow of Godavari River and obstructing freshwater discharge and sediment load into the estuary and mangroves (Malini & Rao 2004). Large-scale deforestation and loss of aquatic habitats in the upper catchments of Godavari River, such as that found in and around the Papikonda National Park (Aditya & Ganesh 2019) which is ~80 km upstream of the estuary, also exacerbates the negative impacts on the estuarine biodiversity.

During the present study, we noticed a number of aquaculture ponds located very close to the mangrove forests, and adjoining the feeder creeks and canals (Image 2). This not only increases the risk of release of exotic fishes and causes degradation of the fringe mangroves, but also increases the risk of introduction of disease in the wild fish community. During the study period, two instances of fish kills were also observed in the Coringa creek draining into the CWS. On further enquiry by the authors, the local fishers informed us that fish kills have become a regular occurrence in the creeks due to the release of untreated effluents by the aquaculture ponds and the industries located upstream. The coastal zones of the East Godavari district are considered among the most polluted in the state (Muktha et al. 2018).

The mangroves of CWS are well-protected and support a diverse aquatic community. However, the mangrove patches at the edge of the sanctuary or the unprotected patches in the district are highly vulnerable to loss and conversion to other land uses, including aquaculture and industries. Bagaria et al. (2021) estimated a loss of 5.81 sq. km of unprotected mangroves in the delta between 1977 and 2015, complemented with a simultaneous rise of 177 km^2 in the area under aquaculture. The study has also highlighted the rapid increase in human settlements and industries and a loss of other natural coastal features, including coastal scrub, mudflats, and riverine vegetation. A recent report by Rao (2021) inferred that an unprotected patch of mangrove drained by a creek near Kakinada harbour had been reported to be reclaimed for city development.

As the unprotected mangroves on the landward side are being lost to land-use changes, climate change is

Image 5. Images of fish species recorded in this study along with their standard lengths whenever available: a—*Acanthurus mata* (56 mm) | b—*Acentrogobius cyanomos* (110 mm) | c—*Lutjanus argentimaculatus* (153 mm) | d—*Butis butis* (120 mm) | e—*Elops machnata*. © Paromita Ray.

Table 2. List of threatened, Near Threatened, and Data Deficient species as per the IUCN Red List of Threatened Species.

	Species name	Main river	Mangroves	Bay	IUCN Red List status
1	*Silonia childreni* (Sykes, 1839)	+	-	-	EN
2	*Tenualosa toli* (Valenciennes, 1847)	+	+	-	VU
3	*Cirrhinus cirrhosus* (Bloch, 1795)	+	+	-	VU
4	*Wallago attu* (Bloch & Schneider, 1801)	+	-	-	VU
5	*Ompok bimaculatus* (Bloch, 1794)	+	-	-	NT
6	*Harpadon nehereus* (Hamilton, 1822)	+	+	+	NT
7	*Protonibea diacanthus* (Lacepède, 1802)	-	+	+	NT
8	*Platycephalus indicus* (Linnaeus, 1758)	+	+	+	DD
9	*Epinephelus tauvina* (Fabricius, 1775)	-	-	+	DD
10	*Acanthopagrus datnia* (Hamilton, 1822)	-	-	+	DD
11	*Rastrelliger kanagurta* (Cuvier, 1816)	+	-	+	DD
12	*Scomberomorus guttatus* (Bloch & Schneider, 1801)	-	-	+	DD
13	*Parapocryptes rictuosus* (Valenciennes, 1837)	-	+	-	DD
14	*Taenioides cirratus* (Blyth, 1860)	+	+	-	DD
15	*Psettodes erumei* (Bloch & Schneider, 1801)	+	-	+	DD
16	*Cynoglossus arel* (Bloch & Schneider, 1801)	+	+	+	DD
17	*Megalops cyprinoides* (Broussonet, 1782)	+	+	+	DD

+—Presence recorded | ——Presence not recorded | EN—Endangered | VU—Vulnerable | NT—Near Threatened | DD—Data Deficient.

driving mangrove loss on the seaward side of the delta. An estimated 15 km^2 of mangroves in the East Godavari district have been lost due to sea-level rise between 1977 and 2015 (Bagaria et al. 2021). Visible signs of seaward changes, including degradation and intrusion of sand into the mangrove forests, were also observed by the authors during the present study (Image 3). This region is also among the coastal stretches of India that are most vulnerable to natural disasters including cyclones and storm surges (Mohapatra et al. 2012). The effects of sea-level rise compounded with the increasing degradation and conversion of the mangroves on the landward side is possibly driving them towards a situation of 'mangrove squeeze'.

In addition to the above threats, regulation of the Godavari River driven by the Polavaram Dam, a large dam being constructed nearly 100 km upstream of the river mouth, will potentially lead to drastic reductions in freshwater and sediment flow into the mangroves and the estuary. Studies from Portugal (Chicharo et al. 2006), China (Jiao et al. 2007) and other parts of the world have shown the negative impacts of damming on estuaries and marine habitats, including changes in salinity regime, nutrient flow, primary productivity and the fish community. Ezcurra et al. (2019) found a rapid coastal recession in otherwise accreting tropical river basins after they were dammed, coupled with losses in fisheries and other ecosystem services. With the presence of nine large dams and a number of smaller dams and irrigation projects, the Godavari River is a highly regulated river system of India. The annual sediment flux in the river basin has already decreased by an estimated 74% (Gupta et al. 2012). The Polavaram Dam has a high likelihood of exacerbating the downstream impacts by restricting the sediment discharge and further altering the freshwater flow regime, both of which play important roles in the sustenance of the mangroves as well as in structuring the estuarine fish assemblages. It will, therefore, be crucial to regularly monitor the estuary and its fish community once the dam becomes functional in the near future.

CONCLUSION AND RECOMMENDATIONS

This study documented the rich finfish diversity of the dynamic Godavari River estuarine complex. This estuary complex, formed by India's largest peninsular river, is undergoing rapid changes driven by number of anthropogenic factors coupled with sea-level rise, coastal erosion and natural disasters including cyclones. While the protected mangroves of the CWS do provide a crucial refuge for estuarine and juvenile marine fishes, it

Image 6. Images of fish species recorded in this study along with their standard lengths whenever available: a—*Trachinotus mookalee* (86 mm) | b—*Triacanthus biaculeatus* (129 mm) | c—*Terapon jarbua* (37 mm) | d—*Jaydia queketti* (88 mm) | e—*Trypauchen vagina*. © Paromita Ray.

is important to adopt a holistic and prescient approach to protect the unprotected coastal habitats of the region. As this study suggests, various fish species are utilizing the different estuarine habitats of the Godavari delta. Few migratory and conservation-concern species such as the 'Hilsa' or 'Pulasa' have also been recorded in this estuary. Therefore, to better manage the threats, and to protect the aquatic ecosystems of the East Godavari district, it is crucial to understand and acknowledge the importance of maintaining the ecological connectivity, both between and within the riverscape and the various estuarine habitats, including the river mouth, the mangrove-lined creeks and the bay. The information collected in this study will serve as a baseline to monitor future changes in the fish community of this region, driven by various anthropogenic and natural stressors.

The Polavaram Dam is already under construction, but it is still important to focus on mitigating the negative impacts on the riverine habitats, both upstream and downstream. The minimum freshwater flows to the downstream habitats must be ensured by the dam authorities, taking in consideration the river's natural pattern of seasonal variation in freshwater discharge. Alongside this, it is also important to recognize the negative impacts of stocking and introduction of non-native fish species as a mitigation measure. Several non-native species have been recorded in this study that were introduced either through fisheries or accidentally through aquaculture and the aquarium industry. The district authorities and the fisheries department need to take immediate steps to address this issue, while strictly prohibiting the stocking of non-native fishes in the reservoir, canals or aquaculture ponds in the district. The fisheries department can encourage protection of the carp and catfish species that are native to the Godavari River basin such as the threatened *Silonia childreni*.

We recommend mapping of the unprotected and degraded patches of mangroves in the delta region of

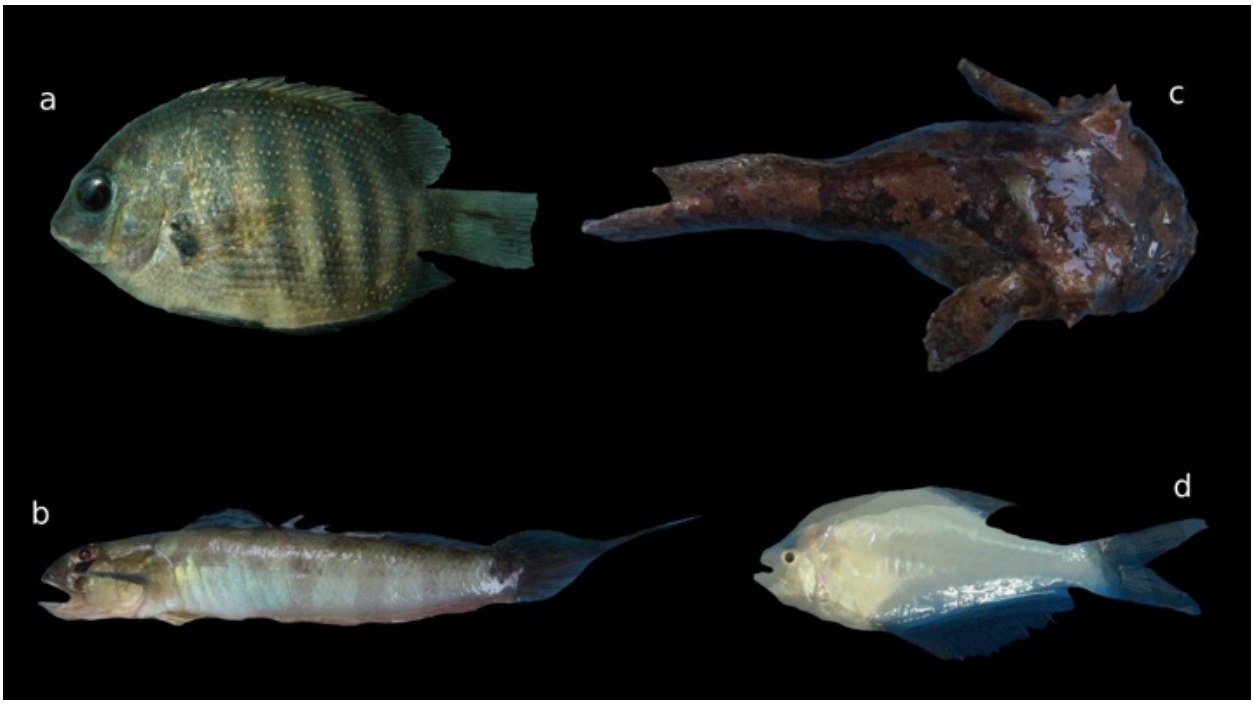

Image 7. Images of fish species recorded in this study along with their standard lengths whenever available: a—*Etroplus suratensis* (71 mm) | b—*Oxyurichthys microlepis* (72 mm) | c—*Allenbatrachus grunniens* | d—*Kurtus indicus* (62 mm). © Paromita Ray.

the district that serve as important nursery habitats for the fish species. This would help in identifying and prioritizing the most vulnerable stretches for focused conservation efforts. Declaring the most degraded and vulnerable mangroves as 'eco-sensitive zones' or 'community reserves' would provide them with basic protection from future conversions and losses. The authorities may follow this with restoration of the degraded mangrove patches. A similar prioritization exercise should also be carried out for other coastal habitats of the estuary, including the unprotected creeks, intertidal zones, mudflats, river banks and the river mouth.

Additionally, a minimum buffer should be allowed around the mangrove forests and the creeks on the landward side to allow them to maintain their structural integrity and landward shift driven by sea-level rise. The aquaculture ponds should particularly be located at a minimum distance away from the mangrove forests and the creeks. Strict monitoring of the ponds, as per the guidelines prescribed by the Coastal Aquaculture Authority of India, should be carried out to prevent untreated effluent discharge and release of non-native species into the natural habitats. Since the area under aquaculture in the district continues to grow each year, a scientific study is recommended that would assess the ecological capacity of this estuarine region to support this industry along with assessing the extant negative ecological and socio-economic impacts of the same. The policies pertaining to captive fisheries should actively encourage sustainable aquaculture practices rather than focusing on maximization of short-term economic gains.

The district authorities should also enhance monitoring of destructive activities in the river basin such as sand-mining, deforestation of the riparian zones, and conversion of river banks to other land-uses. In addition, the government should especially take actions to stop illegal mining of the river bed in the district, proactively monitor the pollution levels in the river, mangroves, and the associated creeks and canals and initiate action against the industries and aquaculture ponds found releasing untreated effluents into the estuary, as prescribed by law.

Garnering the support of local communities and other stakeholders is crucial for the long-term conservation and management of the Godavari estuarine complex and its associated biodiversity. For generating local support, district and village-level organizations such as the panchayat, self-help groups, fishers' collectives, and aquaculture collectives can be leveraged. Regular and focused campaigns would be helpful to improve awareness as well as generating local stewardship for

sustainable fisheries and biodiversity conservation. Such awareness programs should also be developed for policy makers, planners, and stakeholders from the agricultural and industrial sectors since their actions may also have serious impacts on the aquatic ecosystems of the district. Along with this, further inter-disciplinary studies are important to understand the different features of this estuarine complex including biological, ecological, social, cultural, and economic complexities.

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