

**‘Trophic-switch’ by catfish community from predation to scavenging modulated by human food discard in an estuarine bay**

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**Abstract:**

Benthic predatory catfishes are voracious and opportunistic predators and can easily shift their diet according to the availability of prey. In this study, feeding ecology of catfishes from two adjacent habitats of an estuarine bay are compared. The lower bay was relatively pristine as compared to upper bay, and was represented by two families of catfishes- *Plotosidae* and *Ariidae*, while upper bay represented only Ariid catfishes. Gut content analysis revealed that catfish predators from lower bay consumed conventional prey like teleosts and benthic invertebrates with a linear pattern of ontogenetic dietary shift. *Plicofolis dussumeiri* and *Plotosus canius* occupied the position of top predators in the lower bay and were specialised feeders. Other predators like *Plotosus lineatus*, *Arius arius*, *Arius jella* and *Arius maculatus* were generalist feeders occupying the position of mesopredators. However, in upper bay, the catfish predators, represented by *Arius maculatus*, *Arius jella* and *Arius arius* predominantly fed on human discarded food. The easily available human food in the form of chicken, corn, and rice as noted from the investigated guts, show altered trophic guilds of Ariid catfishes wherein only mid to large-sized catfish community was noted in this bay. A distinct ‘trophic-switch’ altered the trophic function from predation to scavenging was observed in their feeding behaviour. The anthropogenic impact in the form of unmanaged organic waste alters the role of predatory catfishes thereby restructuring the food web that may lead to unknown changes in the estuarine benthic ecosystems resulting in reduced ecosystem services.

**Keywords:** Predatory catfishes; *Plotosidae*; *Ariidae*; trophic-switch; human food discard; scavenging; benthic.

## **Introduction:**

Human drivers have the potential to significantly modify and disrupt species interactions within ecosystems that have previously been stable and unaffected by human influence (Rodewald et al. 2011). The available evidence indicates that the presence of readily accessible human-made food has the capacity to modify trophic cascades. According to Jefferies (2000), the provision of anthropogenic discarded food subsidies can have varying effects on food webs, depending on factors such as biomass and trophic levels involved. These subsidies can either contribute to the stabilization of food webs (Serre et al. 2022; Demeny et al. 2019; Oro et al. 2013) or lead to their destabilization. Agriculture, livestock farming, hunting, fishing, dumping waste food as garbage into waterbodies and landfills, and intentionally feeding animals are all examples of anthropogenic food production (Oro et al. 2013). Wet waste is mostly food waste, which accounts for over 50% of hospitality industry waste and up to a third of food consumed in this sector (Omidiani and Hashemi Hezaveh 2016). Proximity to habitation, kitchen waste and discarded food has shown immense influence on Australian dingo (Newsome et al. 2014), black bear, racoons and European red fox (Bino et al. 2010) and many more species globally. According to Rodewald et al. (2011), when synanthropic predators receive significant support from anthropogenic resources, there is a proposed disconnection between predator-prey interactions. Hence, it is crucial to take into account the abundance of resources and the distribution of predators in order to comprehend their functional significance, particularly in regions where there is a surplus of food provided by humans (Oro et al. 2013). The provision of food by humans can result in an augmentation of predator populations (Reshamwala et al. 2018). This is due to the fact that the dietary preferences of predators are modified to incorporate the additional food subsidy (Ciucci et al. 2020). Consequently, various life-history parameters, including survival, reproduction, and social behaviour, are altered in a manner that can either benefit or harm the predator (Julien et al. 2014; Parsons et al. 2022). Furthermore, predators may also modify their home ranges, activities, and movements in response to the availability of human-provided foods (Petroelje et al. 2019). In certain cases, these alterations had an indirect impact on coexisting species through the amplification of predation or competition (Manlick and Pauli 2020).

Megabenthic predators, which refer to predators larger than 1 cm (Stratmann et al. 2020) that are specifically adapted to benthic habitats, play a significant role in the benthic food chain. Siluriform are a large group of Ostariophysian fishes, with ancestral benthic feeding habit (Bruton 1996). They have specialized morphological, behavioral and ecological traits which make them efficient predators in fresh water but not so much in marine environment. Mostly, they are non-aggressive, stalking, nocturnal predators that hunt in turbid water using mostly non-visual senses (Bruton 1996; Pohlmann

et al. 2001). Their dietary distinction between and within freshwater, marine, and estuarine species is notable (Pusey et al. 2020) as a result of the availability of prey. Due to high plasticity, catfish species can very well segregate their niche with respect to habitat (Tilney and Hecht 1990).

Catfishes efficiently learn and specialize for newly available prey like European catfish, *Silurus glanis*, a freshwater apex predator, from lakes in Czech Republic, , adopted a feeding strategy targeting spawning grounds of cyprinids (Vejřík et al. 2017). European catfish have synchronized their feeding to nocturnally migrating endangered lampreys on the way to upstream sites of Dordogne and Garonne rivers in Europe (Boulêtreau et al. 2020). These fast adaptive traits have made them invasive in Chesapeake Bay apparently incurring economic losses as they consume commercial species of American shad, blueback herring, alewife, American eel, and blue crabs (Schmitt 2018). The freshwater piscivorous catfish *Pylodictis olivaris*, suppressed native fish communities in two coastal rivers in North Carolina (Contentnea Creek and the Northeast Cape Fear River; Pine III et al. 2005).

Only two families- Ariidae and Plotosidae have been successfully able to colonize in marine environment and they have precocial life histories that are suited to highly competitive environments (Bruton 1996). Marine catfishes are recognized as one of the key megabenthic predators (Krumme et al. 2008; Farooq et al. 2017) wherein their success can be attributed to their ability to shift from one prey to another with respect to its availability and readily adapt to any small changes in the environment (Bruton 1979; Vejřík et al. 2017 (b); Vejřík et al. 2017(a); Copp et al. 2009; Cucheousset et al. 2012; 2018). *Plotosus canius*, from mangrove estuaries of Malaysia and Bangladesh were benthic carnivore, feeding mostly on brachyuran crabs, shrimps, bivalves, and fishes (Leh et al. 2012; Islam et al. 2021). Adult marine catfishes (Ariidae) are known to use floodplains in Australian rivers as temporary feeding grounds (Pusey et al. 2020). Some overlap and a degree of specialization are notable in two species of *Galeichthys*, wherein *Galeichthys feliceps*, which occur in marine, estuarine and tidal reaches, fed over sandy and muddy substrata in marine and estuarine habitat, while *G. ater* which were exclusively marine, fed over reefs, along the south-east coast of South Africa (Tilney and Hecht 1990). Morphologically well adapted to their respective habitat both species consumed common prey with the former feeding additionally on echinurids while later on cephalopods (Tilney and Hecht 1990). Thirteen species of ariid catfishes from tropical estuarine waters of the Gulf of Carpentaria, Australia were categorized into three feeding guilds- Piscivores, molluscivores, and polychaete feeders. These preferences were due to the size and arrangement of the palatine teeth and gape (Blabber et al. 1994). On the southwest coast of India, *Arius maculatus* showed seasonal plasticity in the diet by specifically feeding on fish in pre-monsoon but on diverse prey in post-monsoon (Prasannakumar et al. 2020). Trophodynamics of *Arius maculatus*, *A. subrostratus*, *A. arius* and *Mystus gulio* from Cochin estuary

showed specialized feeding preference for crustaceans and molluscs (Maitra et al. 2019). The African catfish *Clarias gariepinus* avidly feeds on any dead or decaying organic biomass and is known to grow well on butchery waste, fish meal, poultry waste (Orisasona 2018) and poultry viscera (Adekunmisi et al. 2004; Cayen et al. 2016; Mamoon et al. 2018). Not only animal but plant-based brans of various grains including pulses, organic and brewery waste have proven productive and profitable (Hoffman et al. 1997; Munguti et al. 2012; Hammed et al. 2012; Agbabiaka and Ezeafulukwe 2013; Fakunmoju 2014; Yalew et al. 2019; Adewale 2021; Igbang et al. 2021). Kitchen waste with both animal and plant protein produces significantly higher growth in catfish (Sambhu 2004). This characteristic makes them ideal pond culture species- cost-efficient profitable aquaculture. But considering their predatory and voracious habit, it is not recommended to culture them in natural water bodies with other species (Biswas 2014). Additionally, catfish can also benefit from the feed used as bait for recreational fishing (Vejřík et al. 2019).

In the context of the present study area, food preferences by catfish have a profound influence, as natural estuarine habitats are perturbed with respect to the benthic food chain, trophic transfer, and overall ecosystem functioning. Species with a high degree of flexibility can live in or near human-inhabited places, where they may end up utilizing conveniently accessible food supplies such as human cultivations and rubbish. (Sabbatini et al. 2006). Human influence on the estuaries has led to profound changes, specifically in the regions that are highly urbanized with unabated pollution and waste disposal. Quantification of kitchen waste dumped into water bodies poses a great challenge due to its decentralized and unregulated nature. Most of the other species fail to cope with disturbances that may or may not be natural, and therefore the dominance of catfishes is apparent in the long run. The extent of variation can be significantly influenced by factors such as population density, the presence of waste management infrastructure, cultural practices, and levels of awareness (Tekin and Ilyasov 2017). The present study investigates the population of megabenthic predatory catfish communities in such disturbed habitat while comparing it to relatively pristine adjacent habitat.

The study area, Caranzalem Bay is represented by two catfish families viz; *Plotosidae* and *Ariidae*- medium to large-sized demersal catfishes mostly inhabiting estuarine and marine environments in tropical and subtropical regions (Giarrizzo and Saint-Paul 2008). Ariid catfishes (~25 cm) comprise a significant component of catch in Caranzalem Bay, as are known to dominate the benthic fish biomass (Paul et al. 2019). Since they are not commercially important, they are often either discarded as bycatch or sold at very low market value. Plotosid catfishes, though not as dominant as Ariids in biomass, are discarded as well because they have poisonous spines and are non-consumable. Catfishes play an

important but largely unrecognized role in the estuarine ecosystem, particularly in the benthic food chain.

Previous studies have primarily focused on investigating the impacts of human-induced food subsidies on predators inhabiting terrestrial ecosystems but the impact of these factors on marine predators has not been extensively investigated. Few studies demonstrate the fishery bycatch discard can lead to a trophic shift in marine predators and subsequently trigger trophic cascades within marine ecosystems. However, the impact of regularly discarded human food on the catfish population has not been investigated. We hypothesize that the introduction of human discarded food into the ecosystem will alter the feeding behavior of the catfish population.

The main objectives of this study were 1. To identify predatory catfish species from the relatively pristine and perturbed habitat of the estuary. 2. To compare the feeding preferences of predatory catfish in both habitats 3. Influence of body size of predators on their feeding preferences.

## **Materials and methods:**

### **Study Area:**

This study was conducted from August 2019 to November 2022 at Caranzalem Bay, Goa along the Eastern Arabian Sea situated between 15°27'56''N 73°47'51''E and 15°30'14'' N 73°49'46''E (Fig. 1). This study assesses the distribution of catfish species with respect to their feeding at two adjacent comparable habitats in the Mandovi estuary: the relatively unaffected lower bay known as Caranzalem bay, and the upper bay which has been subject to anthropogenic disturbances. The Mandovi estuary encompasses a length of ~75 km and drainage area of ~1895 km<sup>2</sup> (Qasim and Sen Gupta 1981). The estuary mouth is 3.2 km wide and narrows to 0.25 km upstream. The estuary receives 660 cm of rain annually (Shetye et al. 2007). River runoff is greater during the monsoon season (June to September, ~258 m<sup>3</sup>/s, measured at the head) than it is during the post- and pre-monsoon season (November to May, ~6 m<sup>3</sup>/s, Shynu et al. 2015). Therefore, the Mandovi estuary experiences extreme seasonal variability with almost freshwater dominance during the June– September months and nearly marine dominance during the post-monsoon and premonsoon seasons (Goankar et al. 2021). At spring and neap tides, the Mandovi estuary experiences tidal ranges of approximately 2.3 and 1.5 metres, respectively. During periods of low precipitation, tidal oscillations can be observed, leading to the penetration of saline waters up to approximately 45 km upstream from the mouth of the river. In this estuary, tides greatly influence the current (Veerasingam et al. 2015). Dissolved oxygen (DO) in both surface and bottom waters displays a clear pattern of decreasing concentration from the upstream (head) to downstream (mouth) sections of the estuary because solubility of oxygen in seawater is

inversely proportional to salinity (De Sousa and Gupta 1985). Temperature remains constant throughout the year ( $29.82 \pm 0.48^{\circ}\text{C}$ ; De Sousa and Gupta 1985). In the present case, perturbation refers to leftover human food discard in the benthic habitat. Both the banks of Mandovi mouth are occupied by residential and commercial establishments with several ferries, small boats, and cruises for tourists as well as a fishing harbor. Although small, the city is urbanized catering a significant floating population due to tourist influx, and thus has a high number of restaurants, hotels, floating hotels, and casinos. Coracle fishing is conducted by fishermen in close proximity to floating establishments such as casinos and restaurants. The Mandovi receives approximately  $5.21 \times 10^6 \text{ m}^3$  of sewage and their effluents per year (Kessarkar et al. 2009). Panjim is situated on the left bank and Reis Margos town is situated on the right bank of Mandovi river. The population of Panjim city is approximate 157000 and Reis Margos town has population of 8053 in 2023 (Annon 2023). The city has a regulated waste management system in place and a robust law for solid waste disposal. Pertinently, it was expected to have the least impact on the megabenthic catfish but the present results contradict this notion.

#### **Sample Collection:**

Specimens of catfish were obtained from routine beach-seine, coracle fishing, and gillnet operations specifically operated in the study area (Fig. 1). The beach seine net had a mesh size of 44mm with a length of 1700m long and a height of 20m. The total sample size was collected from a total of 200 operations throughout the study period. The gillnet utilized had a mesh size of 1cm with a length of 150m and a height of 3m. Samples were immediately stored in the ice box and taken to the laboratory for further analysis.

#### **Sample Processing:**

Fish samples were washed, counted, and identified to species level using the standard FAO species identification sheets, Fishbase (Froese and Pauly 2023) database, and the World Register of Marine Species (WORMS; Ah Yong et al. 2023) in the laboratory. Morphometric measurements like standard length and the weight of the fish samples along with photographs were documented. Specimens were divided into three size categories:  $>10 \text{ cm}$ ,  $10\text{--}20 \text{ cm}$ , and  $<20 \text{ cm}$ . Samples were then dissected and the gut was removed and stored in 5% formalin until further investigation of prey items. Following dissection, the stomach contents were rinsed in a petri dish and sieved (on 300  $\mu\text{m}$ ), then examined with a stereo-zoom microscope (Nikon SMZ18). Initially, five major taxonomic categories of prey were identified: Teleosts, Crustaceans, Molluscs, Polychaetes, and human food discard. Moreover, the

crustaceans were categorized into Penaeids, Brachyurans, Pagurids, Isopods, Amphipods, Mysids, and Copepods. All prey items were counted and weighed (wet weight) to the closest 0.0001 g.

### Data Analysis:

Using the ratio between the number of empty stomachs and the total number of specimens investigated, the Vacuity Index (VI; Harmelin-Vivien and Bouchon 1976) was determined for each species as a percentage of empty stomachs;

$$VI (\%) = \frac{\text{No. of empty stomach}}{\text{No. of stomachs examined}} \times 100$$

The contribution of various prey items was evaluated by calculating their weight proportion. (W%; Hyslop 1980)

$$\%W = \frac{W_i}{\sum_1^i W_i} * 100$$

Where,  $W_i$  is the weight of prey of a particular taxon  $i$ .

Levins' measure of niche breadth was calculated (Krebs 1999).

$$\hat{B} = \frac{1}{\sum p_i^2}$$

$$\hat{B}_A = \frac{(B - 1)}{(n - 1)}$$

Where  $\hat{B}$  is Levins' measure of niche breadth;  $\hat{B}_A$  is Levins' standardized niche breadth; and  $n$  is the number of prey categories.  $\hat{B}_A$  values range between 0 (species consumes a single item/specialized feeding mode) and 1 (species exploits available items in equal proportion or generalist feeder). Values of  $\hat{B}_A$  are considered high when higher than 0.6, moderate, when between 0.4 and 0.6 and low when below 0.4

According to the contribution of each taxon from distinct groups, trophic levels of the prey groups were adapted based on local prey composition. The values of trophic level of each identified species of prey were taken from Ebert and Bizzarro (2007) and Cortés (1999). Each prey taxon's contribution and trophic levels were used to compute predator trophic levels.

$$TL = 1 + \left( \sum_1^i P_i * TL_i \right)$$

Where  $TL_i$  is the trophic level of each prey category  $i$  and  $P_i$  is the proportion of prey category  $i$  fed by the predator which can be calculated as number of prey individuals of category  $i$  divided by total number of individuals of all prey categories consumed by that predator.

Using multivariate analysis, we characterised the general feeding patterns of the catfish communities and investigated their dynamic feeding relationships. The similarity percentage analysis (SIMPER) of dietary overlap between catfishes of the family Ariidae found in both habitats (upper bay and lower bay) was carried out to determine the most important prey categories that contribute to the variation in diet (PRIMER v6; Clarke and Gorley 2005). Using nonmetric multidimensional scaling (nMDS) and Bray-Curtis dissimilarities, the foraging patterns of various predators were described. nMDS creates a two-dimensional graphical representation of fish feeding behaviour by clustering groups with similar feeding (e.g., carnivores vs omnivores) and emphasizing sample groups that are outliers (e.g., a specialised predator from a group of generalist predators because it feeds on a specific food item; West et al. 2003). Two-way analysis of variance (ANOVA) without replication was used to understand the significant difference between the feeding preference of predators of two habitats. p-values of  $<0.05$  was considered significant.

## **Results:**

In the present study, the lower bay was represented by two catfish families, Plotosidae and Ariidae. Further, Plotosidae was represented by *Plotosus lineatus* and *Plotosus canius*, while Ariidae was represented by *Arius arius*, *Arius maculatus*, *Arius jella* and *Plicofollis dussumeiri* (Fig. 1). The number of samples collected from lower bay were 800, of which 315 were *Arius maculatus*, 187 were *Arius arius*, 65 were *Arius jella*, 33 were *Plicofollis dussumeiri*, 164 were *Plotosus lineatus*, and 36 were *Plotosus canius* (Table: 1). The mean length and biomass per individual of *Plotosus lineatus* were 13.2 cm and 20.86 g, 19.9 cm and 116.5 g for *Plotosus canius*, 14.8 cm and 36.32 g for *Arius maculatus*, 20.3 cm and 94.66 g for *Plicofollis dussumeiri*, 15.7 cm and 45.06 g for *Arius arius*, 15.2 cm and 41.93 g for *Arius jella* (Table: 1). Mean prey per predator biomass was highest for *Plotosus canius* and *Plicofollis dussumeiri* in lower bay region (Table: 1). In upper bay, 432 samples were collected represented by three species of Ariidae (Table: 1). *Arius maculatus* were 122, *Arius arius* were 154 and *Arius jella* were 156 (Table: 1). Mean length and biomass per individual for *Arius maculatus* was 24.6 cm and 132.94 g, *Arius arius* was 26.5 cm and 139 g, and *Arius jella* was 26.2 cm and 136 g. The mean biomass of prey per predator was highest for *Arius jella* in the upper bay region. Vacuity Index was highest for *Arius jella* and lowest for *Plicofollis dussumeiri* in the lower bay while for the upper bay, the vacuity index was nil for all the investigated predators (Table: 1). Niche breadth



was highest for *Arius jella* and lowest for *Plicofollis dussumeiri*. *Arius arius* and *Plotosus lineatus* had the same niche breadth. While catfishes from the upper bay had a very narrow niche breadth (Table: 1). Catfishes from the lower bay exhibited niche breadth ranging from generalist to specialist as they fed on conventional prey categories while catfishes of upper bay region had a narrow niche breadth because they exclusively fed on human food discard (Table: 1).

According to percentage by weight, from lower bay region, *Plotosus lineatus* dominantly fed on teleosts and also crustaceans played substantial role in their diet (Table: 2; Fig. 2). *Arius maculatus*, *Arius arius* and *Arius jella* significantly consumed crustaceans (Table: 2; Fig. 2). Teleosts also formed major component of their diet. *Plicofollis dussumeiri* and *Plotosus canius* dominantly fed on teleosts (Table: 2; Fig. 2). Catfishes from upper bay region were completely dependent on discarded human food therefore the conventional prey individuals were negligible in their diet (Table: 2; Fig. 2).

Catfish predators were classified into three size classes (Table: 3; Fig. 3). Juvenile *Plotosus lineatus* mostly fed on small crustaceans like isopods, small-sized crabs, penaeids, and amphipods. Medium-sized fed on all types of prey and large-sized fed on teleosts and penaeids (Table: 3; Fig. 3). Juvenile *Plotosus canius* exclusively consumed penaeids while adults preyed upon teleosts (Table: 3; Fig. 3). Juvenile *Arius maculatus* largely consumed bivalves. Medium-sized mostly fed on crustaceans like copepods, mysids, amphipods, and polychaetes. Large-sized consumed amphipods and polychaetes (Table: 3; Fig. 3). Juvenile *Plicofollis dussumeiri* fed on polychaetes, medium-sized fed on crustaceans and teleosts. Large-sized predators consumed teleosts (Table: 3; Fig. 3). Juvenile *Arius arius* predominantly consumed copepods and penaeids. Medium-sized fed on almost all prey categories identified and larger-sized fed on teleosts and crustaceans (Table: 3; Fig. 3). Juveniles of *Arius jella* feeds on polychaetes and brachyuran crabs. Medium-sized predators feed on all prey categories while the large ones fed on penaeids and teleosts (Table: 3; Fig. 3). In the upper bay region, juvenile predators for *Arius arius* and *Arius jella* were not encountered during our sampling. All samples collected were in the range of 10-20 cm and <20 cm (Table: 3). Kitchen/ hotel organic waste was a major food item consumed by both groups; however, small number of brachyuran crabs occurred in the gut of *Arius arius*. Catfishes of both sizes, medium and large, primarily fed on kitchen/hotel food discard. (Table: 3; Fig. 3). Insignificant amounts of teleosts and brachyuran crabs were present in the diets of large predators (Fig. 3).

The trophic level of all investigated predators ranged between 1.8 to 4.1 (Table: 1; Fig. 4). *Plicofollis dussumeiri* (4.0) and *Plotosus canius* (4.1) were apex predators while *Arius maculatus*, *Arius jella*, *Arius arius* and *Plotosus lineatus* were mesopredators with a trophic level ranging from 3.7 to 3.8 in

the lower bay region. In upper bay region, the trophic level of all catfishes ranged between 1.8-2.0, were scavengers (Table: 1; Fig. 4).

SIMPER analysis revealed 95.68% dissimilarity in the dietary overlap between Ariidae families from both the region of which human discarded food had the highest contribution (Table: 4). nMDS plot classified catfish predators into three clusters namely top predators, mesopredators and scavengers (Fig. 4). ANOVA, showed a statistical difference (p-value= 0.0048) between the feeding preference of predators from upper and lower bay.

### **Discussion:**

Catfish species have a reputation as voracious feeders (Maitra et al. 2020) occupying a wide trophic stratum (Pusey et al. 2020) in their natural habitat. They have a life history trait advantage of diverse diet, resist environmental extremes (Pusey et al. 2020), and although with low fecundity (Ambily and Nandan 2017) have high success rate.

Segregated habitat preference was notable in the present results wherein Ariid catfish species were present in both the habitats while Plotosid catfishes occupied only lower bay. Plotosids are primarily found in coral and sandy habitats and exhibit a predominantly carnivorous dietary preference (Bayhan and Erguden 2022). The habitat in the upper bay region is characterised by a combination of muddy and rocky substratum with considerable disturbance. Plotosids were exclusively captured from the lower bay due to their preference for this particular habitat. Moreover, the plotosid predators that were identified predominantly exhibited a medium size, suggesting that they may engage in competition with ariid catfish due to their versatile feeding habits and potentially have been outcompeted by them. In the lower bay a relatively undisturbed habitat, the feeding frequency of the predators was low. The average weight of prey was higher for *Plotosus canius* and *Plicofolis dussumeiri* which indicates their feeding on large prey items like teleosts or more individuals of small prey. They predominantly fed on crustaceans and teleosts (mostly blennies, ponies and anchovies) as well as juveniles of commercially important species like *Silago sihama* and *Tenulosa ilisha*. Thus, they get categorised as top predators as per the Trophic level index (Table: 1). Analysis also reveals opportunistic cannibalism by *Plicofolis dussumeiri*. While the other catfish species viz; *Arius maculatus*, *A. arius*, *A. jella*, and *P. lineatus* occupy the position of mesopredators in lower bay feeding predominantly on invertebrates. In prey-predator interactions, body length plays a significant role (Sheldon et al.1977). The trophic level of a fish is known to increase with growth as its efficiency to acquire prey increases due to fully developed sensory capabilities to capture larger and faster prey (Cousins 1987; Warren and Lawton 1987; Scharf et al. 2000; Yogi et al. 2023). Intermediate-size and smaller-size predators have more impact on lower

trophic strata (Rudolf and Allen 2017) as they tend to consume high numbers of smaller prey with high feeding frequency that induces an indirect effect on prey behaviour. Results showed a notable dietary shift with increasing predator size for all the species of catfishes. The medium sized predators were generalist and the extreme sizes were specialized feeders. Being a generalist feeder *Arius jella* (Table: 1) had the highest niche breadth compared to other species while *Plotosus canius* and *Plicofollis dussumeiri* were specialised feeders specifically targeting certain prey species.

The lower bay region depicted a typical classical feeding habit, preference, and trophic level matching earlier description (Ritakumari and Rajukumar 2007; Gunawickrama 2009; Maitra et al. 2020) including the Ariidae species. Although feeding ecology of *Plotosus lineatus* and *Plotosus canius* has been seldom studied from Indian coasts, notably their feeding was similar to other regions (Usman et al. 2013; Clark et al. 2011; Ueng et al. 2022; Samad et al. 2022). For all the species a typical change in feeding preference with increasing size was notable- a linear-exponential trend.

In contrast, the upper bay region had a clustered length-weight relationship compared to the lower bay. In the upper bay (Table: 1) no empty guts were encountered for three Ariid catfish that were specifically feeding on human food discard, implying the overabundance of discarded food. This revealed a complete ‘trophic-switch’ due to a new and easy food resource allowing the catfish community (specifically Ariid species) to ignore other conventional prey communities while other catfish species were absent in the upper bay. Furthermore, the distinction of length-weight linearity was diffused as catfish consumed excessive food items irrespective of their size. It can be inferred that three species of *Arius* spp. can immediately take advantage of drastic change in food resource availability while *Plotosus canius* and *Plicofollis dussumeiri* were eliminated from this habitat. This suggests that Ariids are more opportunistic (with weak length-weight correlation) while there was a significant correlation between the length and weight of catfish predators inhabiting the lower bay. The observed weight gain can be attributed to the consistent consumption of nutritionally rich and readily available food waste discarded by humans.

This ‘trophic-switch’ from carnivory to scavenging changes the function and releases the predatory pressure on lower benthic strata. This dietary preference alters the catfish community behaviour almost simulating stall feeding. Notably the smallest size class (>10cm) of catfish predators were absent in this habitat probably due to presence of competitive large predators (Table: 3). Specialised predators alter their habitats into small marginal patches (Ryall and Fahrig 2006). Species with a high degree of plasticity, on the other hand, can adapt to living in or near human-inhabited regions due to widely accessible food supplies in the form of discard (Sabbatini et al. 2006). Thus, the catfishes from this benthic habitat can be classified into three feeding guilds namely top predators, mesopredators and

scavengers. Human food discard invokes a new optimal foraging strategy (Townsend and Winfield 1985; Begossi 1992; Cachera et al. 2017) wherein no energy is spent for prey search and acquisition. The catfishes from upper bay need to expend very less energy as the food resource is non-motile, non-evasive and defenceless, thus cost of energy utilised to acquire food is lower as compared to benefits acquired from benthic prey consumption such as teleosts and invertebrates. Human food had far greater gains as predators tend to consume almost negligible benthic prey. Human food can be very nutritious for catfish (Sambhu 2004), so it is expected that the catfishes consuming human food may grow quicker and attain larger sizes compared to the lower bay (Table: 3). Being aggressive, catfishes usually have very few predators although in the lower bay it is notable prey for a Sea Snake (*Enhydrina schistosa*) that almost exclusively consumes mid-sized *Arius* spp. (Tambre et al. 2020). Thereby regulating the population of *Arius* spp. in the lower bay. Having a *k*-selected life history trait the population of this sea snake is in peril due to their frequent occurrence as fishery bycatch. The frequent removal of top predators like sea snakes, can easily benefit mesopredators like catfish, thus releasing them from predatory pressure and increasing their dominance (Heithaus et al. 2008). Easy and ample availability of food resource and releasing them from predatory pressure can act synergistically and aid the Ariid catfish to increase dominance. Predictably, this can lead to dominance of Ariid population, as they have dual competitive advantage over other important benthic predatory species in the bay.

Catfish dominance is known to profoundly influence the changes in biodiversity (Copp et al. 2009) and many species may go locally extinct (Boulétreau et al. 2018). The local habitat of the upper bay will have reduced benthic biodiversity as the dominance will be skewed due to increased Ariid population. Many larger predators that feed on mid-sized benthic species will have deficient prey as catfishes are not preferred prey item thereby disrupting the upper food chain. This bottleneck in the trophic escalation hindered by high catfish population replacing other sensitive species (of similar size) will have impaired ecosystem functioning. The altered community structure of the benthic ecosystem may shift to only scavenging on the discarded food and the overall estuarine habitat will simulate an organic waste converting system which may or may not be efficient and will turn into a degraded ecosystem. The ecological significance of organic waste, such as kitchen waste, is often overlooked in comparison to the impact of inorganic pollutants like heavy metals and plastics. While pollutants that are not recycled tend to accumulate over time, it is important to note that even though they are recycled, continuous disposal of pollutants can still result in their accumulation due to a decrease in the rate of recycling. High discard quantities lead to eutrophication ultimately affecting the estuarine water quality (Vaneckhaute and Fazli 2020).

Human-animal interactions greatly alters the behaviour of organisms, although invariably reported for terrestrial wildlife (Sabbatini et al. 2006; Distefano 2005; Dickman 2010), the present results reveal a direct change in this estuarine habitat. Catfishes, even though, are not in direct competition with humans, can be highly influenced and further alter benthic ecosystem functioning. Estuaries all over the world are under rapid urbanization and present results show how estuarine food chain can be impacted by human disregard. Hence it is important to come up with ecosystem-based waste management strategy to maintain natural trophic functioning and conserve estuarine habitats.

### **Conclusion:**

Catfishes are voracious and opportunistic predators in the benthic food chain. Catfish predation from two adjacent bay habitats, one being anthropogenically perturbed was investigated. Human discarded food was found in the investigated guts of catfish predators from the disturbed bay region. A drastic shift in feeding guild of catfishes was noted. Catfish predators were scavenging on easily available discarded human food in the anthropogenically disturbed bay region. This study signifies the impact of discarded organic waste on the altered trophic behaviour of catfish community in the estuarine habitat and its influence on the overall ecosystem functioning.

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Not applicable.

### **Consent to Publish:**

All authors have given their consent to publish the study in the journal of Environmental Science and Pollution Research if accepted.

### **Author Contributions:**

**Deepa Shashikant Yogi:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Visualization, Writing - Original Draft

**Akshay Naik:** Formal analysis, Investigation, Methodology, Resources.

**Ranjana Yadav:** Formal analysis, Investigation, Methodology.

**Aniket Desai:** Formal analysis, Investigation, Methodology.

**Mandar Nanajkar:** Conceptualization, Supervision, Project administration, Writing - Review and Editing.

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Data can be made available upon request.

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**Tables:**

Table 1: No of gut analysed, Average length, average weight of predators investigated, average weight of prey, No. of empty guts, Vacuity index, Niche breadth, and trophic level of the predators investigated.

Predators	Guts analysed (Bay)	Mean length per individual (cm)	Mean biomass of individual predator (g)	Mean biomass of prey (g)	No of empty guts	Vacuity Index (VI)	Niche breadth	Trophic level
<b>Lower bay</b>								
<i>Plotosus lineatus</i>	164	13.2	20.86	1.39	7	4.3	0.4	3.8
<i>Plotosus canius</i>	36	19.9	116.58	3.19	1	2.8	0.3	4.1
<i>Arius maculatus</i>	315	14.8	36.32	1.41	26	8.3	0.5	3.7
<i>Plicofolis dussumieri</i>	33	20.3	94.66	4.24	0	0	0.2	4
<i>Arius arius</i>	187	15.7	45.06	1.64	14	7.5	0.4	3.8
<i>Arius jella</i>	65	15.2	41.93	1.69	6	9.2	0.6	3.7
<b>Upper bay</b>								
<i>Arius arius</i>	154	26.5	139	6.53	0	0	0.023	1.9
<i>Arius jella</i>	156	26.2	136	9.73	0	0	0	2
<i>Arius maculatus</i>	122	24.6	132.94	5.86	0	0	0.041	1.8

Table: 2: Percent weight of prey consumed by catfish predators from the lower bay.

<b>Prey</b>	<i>Plotosus lineatus</i>	<i>Plotosus canius</i>	<i>Arius maculatus</i>	<i>Arius arius</i>	<i>Arius jella</i>	<i>Plicofolis dussumeiri</i>
Polychaetes	1.4	0.0	11.7	9.9	9.8	0.7
Bivalves	0.0	0.0	0.0	2.9	5.1	0.0
Copepods	3.0	0.0	4.0	0.6	1.4	0.0
Mysis	3.0	0.0	0.8	1.6	0.0	0.0
Amphipods	9.0	0.0	2.0	2.6	4.8	0.5
Isopod	4.6	0.0	4.9	0.0	0.0	0.0
Penaeids	32.6	14.6	32.5	27.8	28.8	10.3
Brachyuran crabs	13.4	0.0	16.5	18.8	30.0	20.1
Teleosts	33.0	85.4	27.6	35.8	20.1	68.5

Table: 3: Classification of catfish based on size for both the study locations.

	Lower Bay						Upper bay		
Size (cm)	<i>Plotosus lineatus</i>	<i>Plotosus canius</i>	<i>Arius maculatus</i>	<i>Plicofollis dussumeiri</i>	<i>Arius arius</i>	<i>Arius jella</i>	<i>Arius arius</i>	<i>Arius jella</i>	<i>Arius maculatus</i>
>10	8	8	32	1	18	5	-	-	-
10 to 20	154	13	248	16	134	51	2	-	11
<20	2	15	35	16	35	9	152	156	111

Table: 4: SIMPER analysis for dietary overlap between two habitats

Species	Av. Abund	Av. Abund	Av. Diss	Contrib%	Cum.%
Chicken/Corn/Rice	0.94	0.00	47.05	49.17	49.17
Fish	0.02	0.24	11.33	11.84	61.01
Polychaetes	0.00	0.16	7.93	8.29	69.30
Penaeids	0.01	0.15	7.37	7.71	77.01
Amphipods	0.00	0.13	6.51	6.80	83.81
Crabs	0.02	0.12	5.07	5.30	89.11
Mysis	0.00	0.07	3.74	3.91	93.01

Groups Ariidae (Upper Bay) and Ariidae (Lower Bay)

Average dissimilarity = 95.68



**Figure Captions:**

**Fig. 1** Study area showing both upper and lower bay regions (Credit: Google Maps)

**Fig. 2** Dominant diet of the investigated predators from lower and upper bay region

**Fig. 3** Ontogenetic dietary shifts observed in the feeding of the investigated predators

**Fig. 4** Trophic levels of catfishes from both the study area identified using nMDS plot

**Fig. 5** Prey identified in the guts of the catfishes from the lower bay a. Dissected gut of predatory catfish, b. *Tenulosa Ilisha*, c. Prey catfish, d. Blenny, e. Mysid, f. Amphipod, g. Polychaetes, h. Brachyuran crab, i. Penaeid shrimp, j. Bivalves. Prey identified in the guts of the catfishes from upper bay region k. Human discarded food- Chicken, l. Chicken and corn, m. Rice.



Figure 1

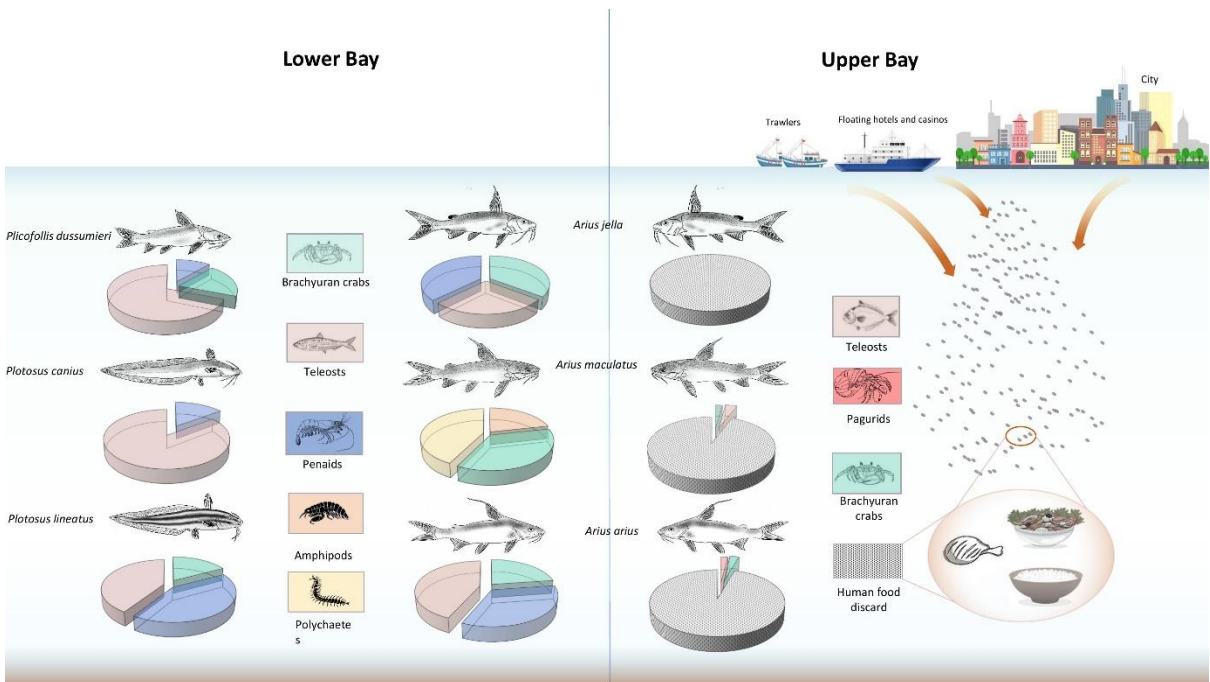


Figure 2

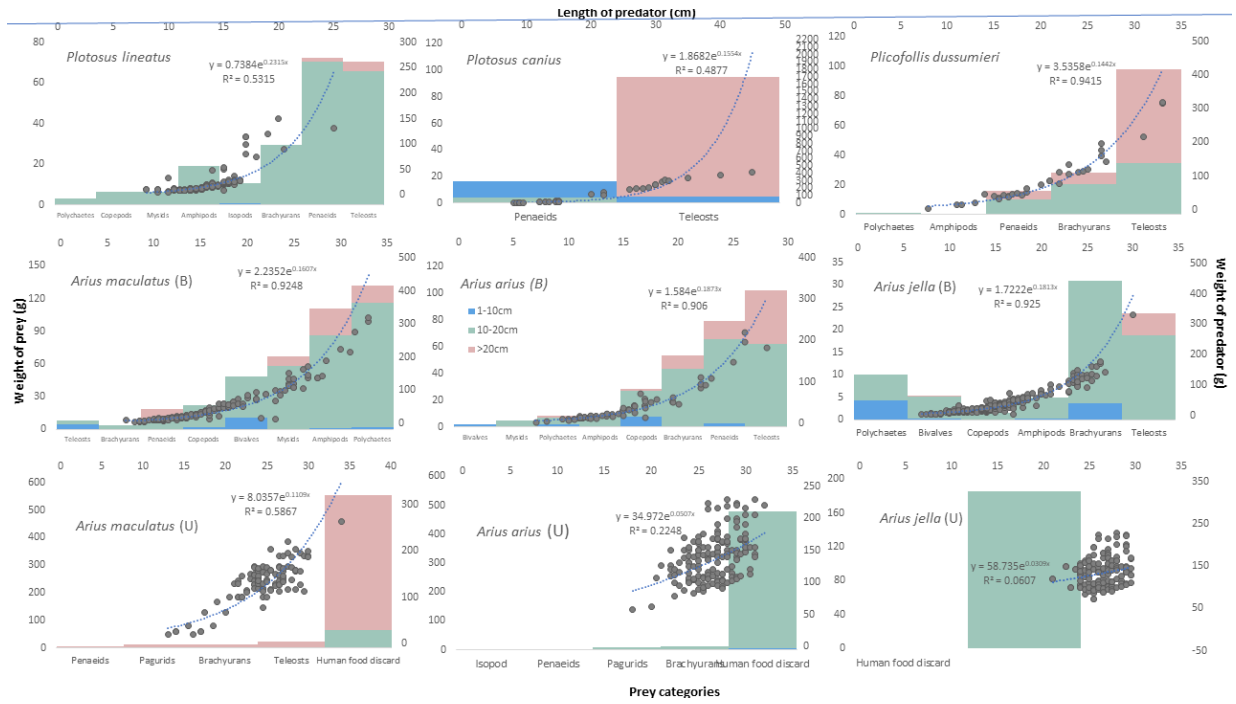


Figure 3

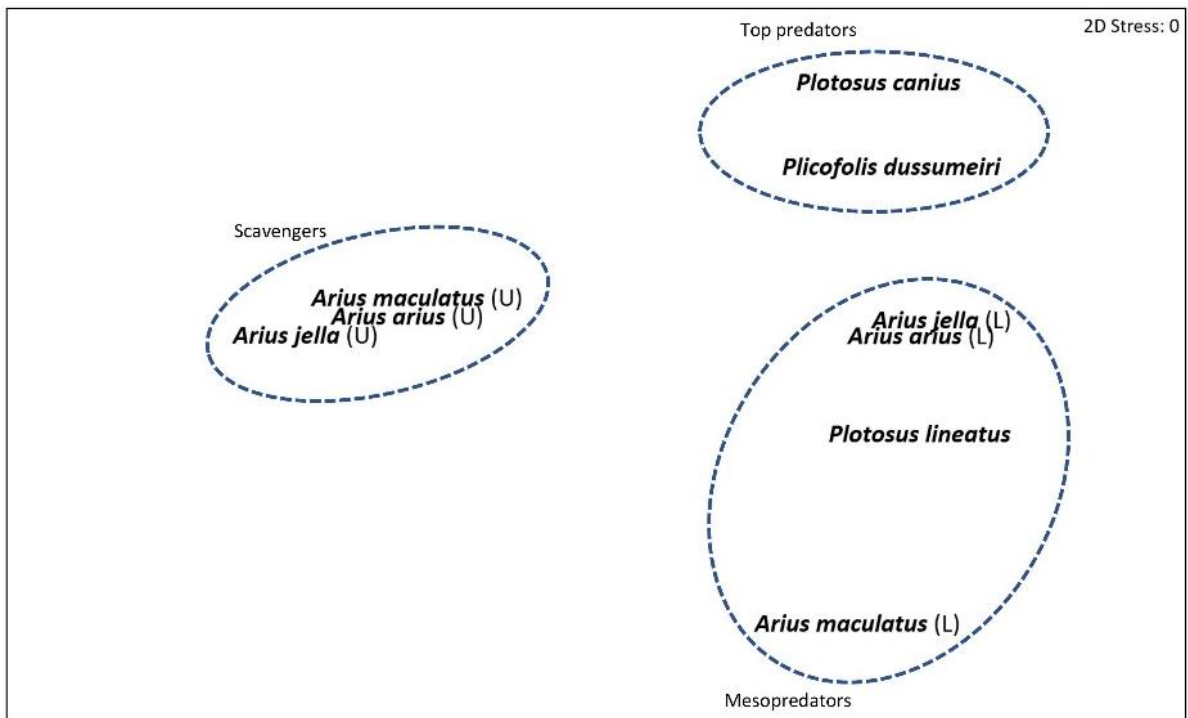


Figure 4



Figure 5