TRANSYLVANIAN REVIEW OF SYSTEMATICAL AND ECOLOGICAL RESEARCH

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Editors

Doru Bănăduc, Kevin Cianfaglione & Angela Curtean-Bănăduc

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Applied Ecology Research Center,
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IN MEMORIAM

Roumen Kirilov KALCHEV

(1951 – 2021)

It is with deep regret that we learned the news that the highly respected and eminent Bulgarian hydrobiologist, Mr. Roumen Kirilov Kalchev has passed away on 12th March 2021.

Mr. Roumen Kalchev was born in Kubrat, Bulgaria. In 1979, he graduated Biology in the University of Rostock, Germany. In 1984, he defended his PhD dissertation “Fluorescence characteristics of some algal species and possibilities for their application for studying primary production of fresh waters” at “Taras Chevchenko” University and the Institute of Plant Physiology of the National Academy of Sciences of Ukraine in Kiev. In the same year he was appointed at the Institute of Zoology, Bulgarian Academy of Sciences (IZ-BAS) as an Assistant Professor (1984) and later as an Associate Professor (2002). In 2015 he received the rank of Professor at the Institute of Biodiversity and Ecosystem Research, BAS (IBER-BAS). Mr. Kalchev was a head of the Phytoplankton Research Group (RG) and Hydrobiology Department at IZ-BAS. Since 2010 he was a head of the Lenthic Ecosystem RG and Section of Biodiversity and Processes in Freshwater Ecosystems at IBER-BAS.

The main focus of Prof. Dr. Roumen Kalchev’s research was the composition and functioning of phytoplankton, the photosynthetic pigments, and measurement of primary production of reservoirs, fishponds, the Danube River and adjacent wetlands, as well as the Black Sea coastal lakes. Professor Kalchev has revealed important relationships between chlorophyll-a and the phytoplankton parameters (taxonomic and functional groups, algal size, abundance, biovolume, etc.). Further, he extended his studies to aquatic chemistry and nutrient cycles, especially the phosphorus and nitrogen limitation of phytoplankton growth; pelagic trophic relationships between solar energy, nutrients, bacterio-, phyto- and zooplankton and assessment of the trophic status and water quality gradients in stagnant water bodies. The results of his studies demonstrated the significance of the trophic relationships in the pelagial for the ecological status improvement through different approaches as catchment regulation and biomanipulation. His original scientific and applied contributions helped to successfully solve problems in the conservation and sustainable use of biological resources in standing natural and artificial water bodies, as well as in the restoration and protection of wetlands.

Some of the research topics of Mr. Kalchev were devoted to threats to biodiversity and ecosystem functions and services. He studied the pollutant loads in rivers, as well as the effects of fertilisers of organic origin and different farming practices on plankton primary production, bacterioplankton, nutrients and water quality characteristics in fish ponds and reservoirs. He had a leading role in the project: “Exploring and assessment of influence of pollution by diffuse sources on ecological status of surface waters (2014-2015), funded by the Ministry of Environment and Water of Bulgaria. His recent studies focused on the impact of invasive alien species, in particular the mussel species of the genus *Dreissena*, on the physical and chemical parameters of water and bacterio-, phyto- and zooplankton in infested reservoirs in Bulgaria.

Mr. Kalchev developed scientific collaborations with colleagues from Austria, Germany, Romania, Hungary, Ukraine, etc. He was an active member of the International Association for Danube Research (IAD), contributing to several expert groups and eight of the IAD Scientific conferences. Mr. Kalchev was also an active member of the Union of Scientists in Bulgaria. He is an author and co-author of more than 150 scientific publications, including a textbook on Ecotoxicology. He was involved in teaching of students at the Biological Faculty of Sofia University.

With the death of Prof. Roumen Kalchev, the scientific community has lost an honourable colleague and hydrobiologist!

The Editors

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Preface

In a global environment in which the climate changes are observed from few decades no more only through scientific studies but also through day by day life experiences of average people which feel and understand allready the presence of the medium and long-term significant change in the “average weather” all over the world, the most comon key words which reflect the general concern are: heating, desertification, rationalisation and surviwing.

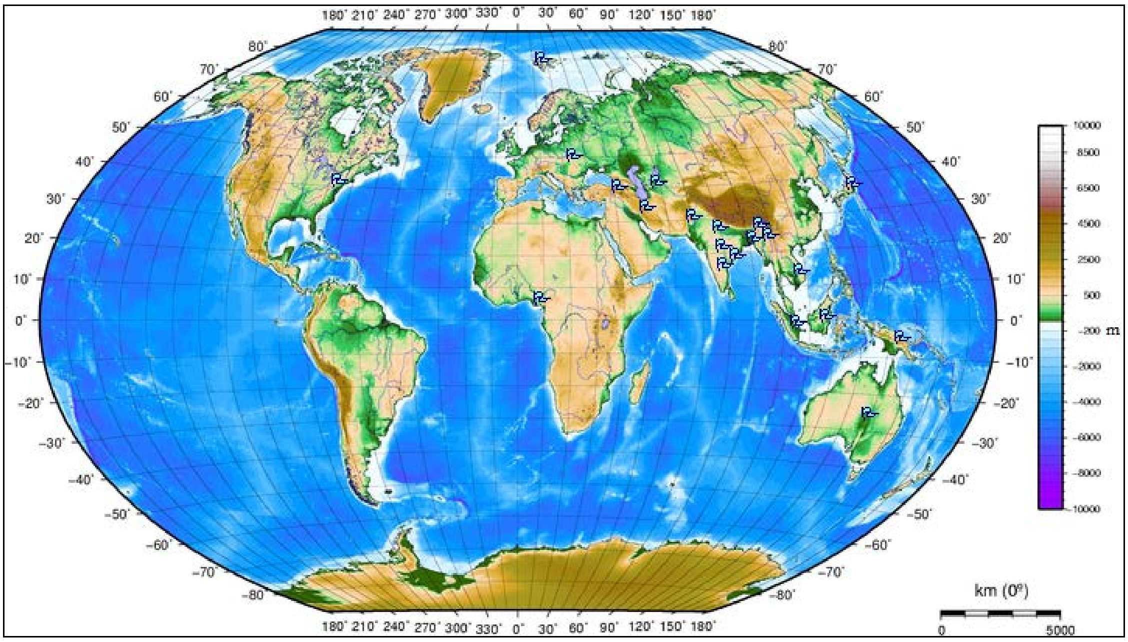
The causes, effects, trends and possibilities of human society to positively intervene to slow down this process or to adapt to it involve a huge variety of aproacess and efforts.

With the fact in mind that these aproaces and efforts shuld be based on genuine scientific understanding, the editors of the *Transylvanian Review of Systematical and Ecological Research* series launch three annual volumes dedicated to the wetlands, volumes resulted mainly as a results of the *Aquatic Biodiversity International Conference*, Sibiu/Romania, 2007-2017.

The therm wetland is used here in the acceptance of the Convention on Wetlands, signed in Ramsar, in 1971, for the conservation and wise use of wetlands and their resources. **Marine/Coastal Wetlands** – Permanent shallow marine waters in most cases less than six metres deep at low tide, includes sea bays and straits; Marine subtidal aquatic beds, includes kelp beds, sea-grass beds, tropical marine meadows; Coral reefs; Rocky marine shores, includes rocky offshore islands, sea cliffs; Sand, shingle or pebble shores, includes sand bars, spits and sandy islets, includes dune systems and humid dune slacks; Estuarine waters, permanent water of estuaries and estuarine systems of deltas; Intertidal mud, sand or salt flats; Intertidal marshes, includes salt marshes, salt meadows, saltings, raised salt marshes, includes tidal brackish and freshwater marshes; Intertidal forested wetlands, includes mangrove swamps, nipah swamps and tidal freshwater swamp forests; Coastal brackish/saline lagoons, brackish to saline lagoons with at least one relatively narrow connection to the sea; Coastal freshwater lagoons, includes freshwater delta lagoons; Karst and other subterranean hydrological systems, marine/coastal. **Inland Wetlands** – Permanent inland deltas; Permanent rivers/streams/creeks, includes waterfalls; Seasonal/intermittent/irregular rivers/streams/creeks; Permanent freshwater lakes (over eight ha), includes large oxbow lakes; Seasonal/intermittent freshwater lakes (over eight ha), includes floodplain lakes; Permanent saline/brackish/alkaline lakes; Seasonal/intermittent saline/brackish/alkaline lakes and flats; Permanent saline/brackish/alkaline marshes/pools; Seasonal/intermittent saline/brackish/alkaline marshes/pools; Permanent freshwater marshes/pools, ponds (below eight ha), marshes and swamps on inorganic soils, with emergent vegetation water-logged for at least most of the growing season; Seasonal/intermittent freshwater marshes/pools on inorganic soils, includes sloughs, potholes, seasonally flooded meadows, sedge marshes; Non-forested peatlands, includes shrub or open bogs, swamps, fens; Alpine wetlands, includes alpine meadows, temporary waters from snowmelt; Tundra wetlands, includes tundra pools, temporary waters from snowmelt; Shrub-dominated wetlands, shrub swamps, shrub-dominated freshwater marshes, shrub carr, alder thicket on inorganic soils; Freshwater, tree-dominated wetlands; includes freshwater swamp forests, seasonally flooded forests, wooded swamps on inorganic soils; Forested peatlands; peatswamp forests; Freshwater springs, oases; Geothermal wetlands; Karst and other subterranean hydrological systems, inland. **Human-made wetlands –** Aquaculture (e. g., fish/shrimp) ponds; Ponds; includes farm ponds, stock ponds, small tanks; (generally below eight ha); Irrigated land, includes irrigation channels and rice fields; Seasonally flooded agricultural land (including intensively managed or grazed wet meadow or pasture); Salt exploitation sites, salt pans, salines, etc.; Water storage areas, reservoirs/barrages/dams/impoundments (generally over eight ha); Excavations; gravel/brick/clay pits; borrow pits, mining pools; Wastewater treatment areas, sewage farms, settling ponds, oxidation basins, etc.; Canals and drainage channels, ditches; Karst and other subterranean hydrological systems, human-made.

The editors of the *Transylvanian Review of Systematical and Ecological Research* started and continue the annual sub-series (*Wetlands Diversity*) as an international scientific debate platform for the wetlands conservation, and not to take in the last moment, some last heavenly “images” of a perishing world …

This volume included variated original researches from diverse wetlands around the world.



The subject areas (⚑) for the published studies in this volume.

No doubt that this new data will develop knowledge and understanding of the ecological status of the wetlands and will continue to evolve.

Acknowledgements

The editors would like to express their sincere gratitude to the authors and the scientific reviewers whose work made the appearance of this volume possible.

The Editors

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URBAN AQUATIC ECOSYSTEMS AS A FACTOR OF THE SPREAD OF ANTIBIOTIC RESISTANT MICROORGANISMS AND RESISTANCE GENES

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KEYWORDS: co-resistance, water quality, antibiotic resistance microorganisms, drinking water sources, resistant genes.

ABSTRACT

In this work, studies have been conducted to detect antibiotic resistance microorganisms and resistance genes in the natural waters of the Uzh River, which flows in the Carpathian region (Ukraine) and flows into the Laborec River in the territory of Slovakia. Among the most common microorganisms of the Uzh River, there has been a high level of resistance to tetracyclines, β-lactams, and antibiotics of the last line of defence (carbapenems, fourth-generation fluoroquinolones). The results of molecular genetic analysis indicate the presence of resistance genes *bla* tet-M, *bla* CTX-M, *bla* TEM, and *bla* KPC in microorganisms of the Enterobacteriaceae family.

ZUSAMMENFASSUNG: Urbane aquatische Ökosysteme als Faktor für die Verbreitung Antibiotika resistenter Organismen und resistenter Genen.

Die vorliegende Arbeit befasst sich mit den Ergebnissen von Untersuchungen über Nachweise Antibiotika resistenter Mikroorganismen und resistenter Gene in den natürlichen Gewässern des Uzh-Flusses, in der Karpatenregion der Ukraine entspringt und auf dem Gebiet der Slowakei in den Laborec-Fluss mündet. Unter den häufigsten nachgewiesenen Mikroorganismen des Uzh-Flusses fanden sich solche, deren Resistenz gegen Tetracycline, β-Lactame und Antibiotika der letzten Aktivitätslinie (Carbapeneme, Fluorchinolone der vierten Generation) hoch war. Die Ergebnisse der molekulargenetischen Analyse weisen auf das Vorkommen der resistenten Gene bla tet-M, bla CTX-M, bla TEM und bla KPC in Mikroorganismen der Familie der Enterobacteriaceae hin.

REZUMAT: Ecosisteme urbane acvatice ca factor al răspândirii microrganismelor rezistente la antibiotice şi a genelor de rezistenţă.

În această lucrare, au fost efectuate studii pentru a detecta microorganismele cu rezistență la antibiotice și genele de rezistență în apele naturale ale râului Uzh, care curge în regiunea Carpaților (Ucraina) și se varsă în râul Laborec pe teritoriul Slovaciei. Printre cele mai frecvente microorganisme ale râului Uzh, a existat un nivel ridicat de rezistență la tetracicline, β-lactame și antibiotice din ultima linie de apărare (carbapeneme, fluorochinolone de generația a patra). Rezultatele analizei genetice moleculare indică prezența genelor de rezistență *bla* tet-M, *bla* CTX-M, *bla* TEM și *bla* KPC în microorganisme din familia Enterobacteriaceae.

INTRODUCTION

Due to industrialized production, there are many pharmaceuticals that became largely accessible worldwide, and their unintentional presence in various ecosystems have a negative impact (Burcea et al., 2020). The resistance development of microorganisms to antibiotic substances has become a global issue of this century. Although antibiotics have been leading medicines used in therapy, the current rapid development of resistance deteriorates their activity and efficacy (Yu et al., 2019). Antibiotic substances may accumulate and spread in the environment, first of all, in water and soils, which making them dangerous pollutants. As far as water takes part in the circulation of elements and is part of food chains, it may also be a key migration factor for genetic resistance determinants. After humans and animal have consumed antibiotics, most of the antibiotic substances that have not been fully digested and disposed of are eliminated from the body with excrements and enter rivers, lakes, and underground waters. The level of antibiotic resistance increases as they enter environmentally unfriendly mediums with a heightened level of pollutants. (Karkman et al., 2017)

Urbanized areas, where large amount of antibiotics enter wastewater treatment plants, are most saturated with antibiotic substances (Martinez et al., 2009). The environmental impact of the growing concentration of antibiotics has been studied insufficiently so far (Grehs et al., 2019), which does not give us a chance to evaluate the multi-resistant strains fully.

When the use of antibiotics grew by many times, the current pandemic triggered considerably the development of antibiotic resistance, which will inevitably result in the appearance of new "super-bacteria", and it again emphasizes the importance of this issue.

Researches of the different regions point to the fast distribution of antibiotic resistance genes (ARGs), particularly – multi-resistant strains of *Klebsiella* spp., which are carriers of extended-spectrum beta-lactamases (ESBL) genes isolated from the Delhi River. In the Danube River (Budapest) were identified a number of multi-resistant microorganisms belonging to the Enterobacteriaceae family, and ESBL resistance genes were found in isolates *Escherichia coli, Klebsiella pneumoniae,* and *Enterobacter* spp. (Kittinger et al., 2016).

Multi-resistant isolates of *Enterococcus faecium* and *Enterococcus faecalis* were identified in the Vistula River (Poland) (Giebułtowicz et al., 2017). In that time, resistance genes CTX-M represented by subgroups CTX-M-1, CTX-M-2, and CTX-M-9 were identified in Enterobacteriaceae family representatives of the Mur River (Austria) (Zarfel et al., 2017).

A significant part of the research on antibiotic resistance is focused on clinical practice research, while this problem is poorly studied in natural ecosystems. But its role is equally important. Sanitary standards for surface water quality and centralized water supply do not provide the study of water for ARGs and even the identification of multi-resistant forms of microorganisms, which makes it impossible to control the ARG's spread.

The progressive evolution of antibiotic resistance leads to the study of mechanisms for developing new methods of surface water quality assessment that will allow continuous control of the circulation of ARGs in water. According these, study about the determination of dominant representatives of the Uzh River microbial communities and their sensitivity to antibiotics in territories with different levels of anthropogenic loading are relevant.

In this study, we aimed to investigate the presence and spread of antibiotic resistance genes in the surface waters organisms of the Uzh River to determine the current state of resistances. Researching into antibiotic resistence of aquatic ecosystems is an essential line of research. That will help study the profiles of antibiotics resistance genes in various urbanized hydroecosystems, which is a priority task elaborating technologies able to eliminate the antibiotics and inactivate the multi-resistant microorganisms and their resistance genes in wastewaters, avoiding cycles of contamination and environmental spread.

MATERIAL AND METHODS

Sampling points

The materials used for the study were the surface waters of the Uzh River (Ukraine). The samples are taken during the summer period, taking into account the physical-chemical parameters of the water as previously researched by us and covered in the works (Bilkey and Nikolaichuk, 2017; Bilkei and Kryvtsova, 2018). Sampling was performed from eight-points, conventionally dividing the territory of the Uzh riverbed into the recreational zone: No. 1 – upstream from the village of Volosianka; the technologically transformed zone – up-No. 2 and downstream No. 4 from the city of Perechyn and 100 m from the site where the Domoradzh Stream (derives from the chemical plant) flows into the Uzh River — No. 3; the urbanized zone – up-No. 5 and downstream from the city of Uzhhorod – No. 6 and agrarian – up-No. 7 and downstream the village of Storozhnytsia – No. 8) (Fig. 1).

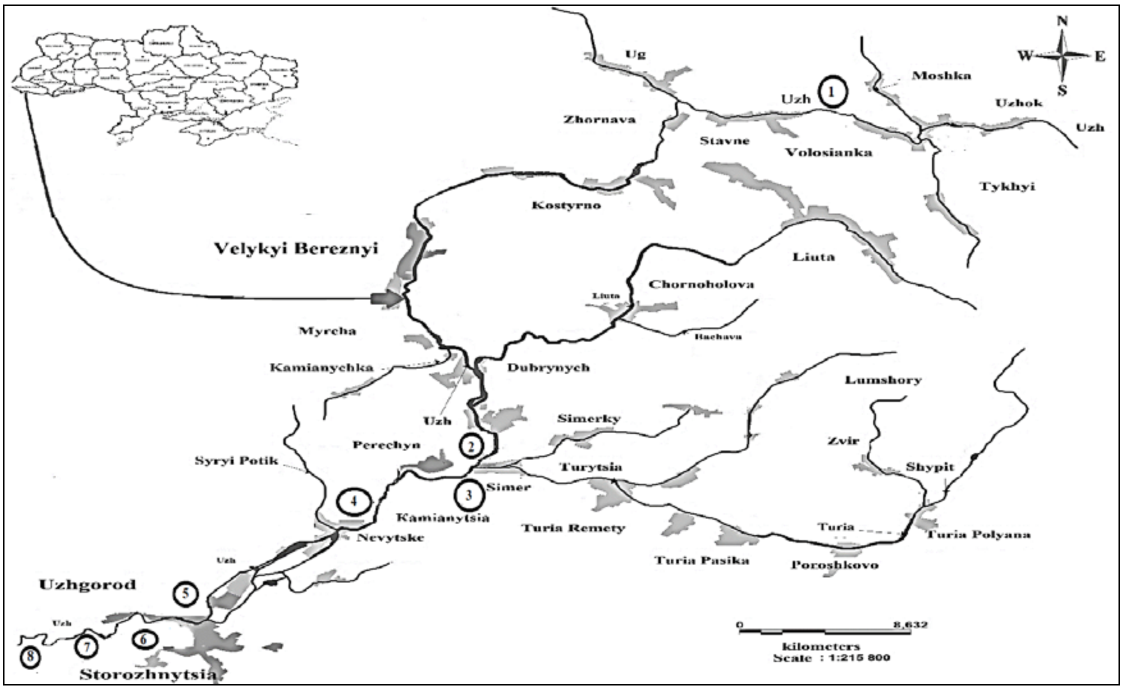

Figure 1: Uzh River study area (No. 1 – recreational zone; No. 2 – No. 4 – technologically transformed zone; No. 5 – No. 6 – urbanized zone; No. 7 – No. 8 – agrarian zone).

Identification of isolated strains and analysis of antibiotic resistance

The water samples collected in sterile vials with a volume of 1,000 ml, were corked with cotton stoppers covered with a paper cap. The water samples were analyzed two hours after sampling. Identification of microorganisms included studying the morphological characteristics of colonies on Hottinger agar (pH ± 7.2) and further differentiation on selective media of Endo, Ploskirev, bismuth-sulfite agar. Chromogenic nutrient medium (Hi Crom UTI Agar, Modified HiMedia, India) used for one-stage isolation and direct identification of the most frequent and significant Enterobacteriaceae for sanitary microbiology. According to the results of biochemical tests (Enterotest 24 and 16) produced by ErbaLachema, Czech Republic, determining the generic and species affiliation of opportunistic bacteria was determined. Strains of Salmonella genome confirmed by Salmonella serum (Denka Seiken, Japan).

Antibiotic resistance of the Enterobacteriaceae isolates determined by the Kirby-Bauer disk (HiMedia) diffusion method according to the European Committee on Antimicrobial Susceptibility Testing (EUCAST). Selection of antibiotics for testing water microorganisms, caused by the growth of the resistance to such groups of antibiotics (tetracyclines, β-lactams) among clinical strains in the investigated region. The isolates were screened for susceptibility to such antibiotics: ampicillin (AMP, 10 μg), ampicillin-sulbactam (AMP/S, 10/10 μg), ceftriaxone (CTR, 30 μg), imipenem (IMP, 10 μg), cefuroxime (CXM, 30 μg), cefoperazone-sulbactam (CFS, 75/30 μg), meropenem (MRP, 10 μg); amikacin (AK, 30 μg); gentamicin (GEN- 10 μg); ciprofloxacin (CIP, 5 μg), levofloxacin (LE, five μg), gatifloxacin (GAT, five μg), norfloxacin (NX, 10 μg), ofloxacin (OF, two μg), lomefloxacin (LOM, 30 μg); tetracycline (TE, 30 μg), and doxycycline (DO, 10 μg). The sterile filter paper disks (six mm in diameter) with antibiotics were placed on the plate previously inoculated with a microbial suspension and incubated at 37 ± 2ºC for 24 hours. The size of inhibition zone diameters surrounding the filter paper disc was measured and compared to the Zone Diameter Interpretive Standards. Each bacterial isolate is classified as susceptible (S), intermediate (I), or resistant (R) to antibiotics, according to the zone diameter interpretation standard recommended by the EUCAST (2018). *Escherichia coli* ATCC 25922 was used as a quality control strain to check the quality of the media and antibiotic discs and the accuracy of the testing procedure. The bacteriological analysis of the water and determination of its antibiotic susceptibility was conducted based on the Microbiological Laboratory of the Department of Genetics, Plant Physiology, and Microbiology of Uzhgorod National University (Ukraine).

Detection of resistance genes

Bacterial DNA were isolated by the method of temperature lysis in TE buffer. Colonies of daily cultures of the tested microorganisms were placed in a centrifuge tube with 500 μl of sterile deionized water suspended with a shaker. Microbial cells precipitated by centrifugation at 10,000 g for one minute. The supernatant was removed, the sediment was resuspended in 100 μl of TE buffer. The tubes were incubated in a solid-state thermostat for 20 minutes at 99°C, and then centrifuged at 10,000 g for one minute. One ml of supernatant was used for polymerase chain reactions. The sets of reagents of “Lytekh” production (Russia) were used for the setting of PCR. The final volume of the reaction mixture was 25 μl. The reaction components were put in according to the manufacturer’s instructions. Positive and negative control was included in the sets and performed according to the manufacturer’s instructions. The resulting products were visualized by electrophoresis (0.5x TE buffer) in 2% agarose gel containing ethidium bromide, followed by viewing in a UV transilluminator. Polymerase chain reaction (PCR) was performed using a detector DTPrime Amplifier (DNA Technology; Russia).

The following sets of PCR-reagents for determination of resistance to antibiotics with electrophoretic end-point detection PCR (NPF Litekh; Russia) were used: the Resistance to carbapenems for identification of bla_{NDM} genes; the Resistance to carbapenems for identification of $bla_{\mathrm{OXA\text{-}48}}$ genes; the Resistance to cephalosporins for identification of $bla_{\mathrm{CTX\text{-}M}}$ genes; the Tetrapol set, for idenfinition of resistance to $bla_{\mathrm{tet\text{-}M}}$ tetracycline.

The other three groups of resistant genes (bla_{TEM}, bla_{KPC}, and bla_{SHV}) were determined according to the protocol. Primers used to amplify the genes of beta-lactamase are presented in table 1. *E. coli* ATCC 25922 was used as a negative control. For positive controls were used, *Klebsiella pneumoniae* ATCC BAA-1705 (bla_{KPC} genes), *K. pneumoniae* ATCC 5103 (bla_{TEM} genes), and *K. pneumoniae* ATCC 700603 (bla_{SHV} genes).

Table 1: Primers used for the detection of antibiotic-resistant genes.

Gene targeted	Sequence 5'-3'	Aplicone size, bp	References
*bla*KPC	5'-GCGGAACCCCTATTTG-3' (F) 5'-CTTGTCATCCTTGTTAGGCG-3' (R)	798	Poirel et al., 2011
*bla*TEM	5'-GCGGAACCCCTATTTG-3' (F) 5'-ACCAATGCTTAATCAGTGAG-3' (R)	964	Olesen et al., 2004
*bla*SHV	5'-TTATCTCCCTGTTAGCCACC-3' (F) 5'-GATTTGCTGATTTCGCTCGG-3' (R)	795	Arlet et al., 1997

RESULTS AND DISCUSSION

Facultative microbial communities in Uzh River water

The results of our research showed that microorganisms of the Enterobacteriaceae predominantly represented the gram-negative constituent of the microbial communities of the Uzh River. Antibiotic-resistant microorganisms were not detected in the recreational area. It was also established that the most significant number of opportunistic microorganisms fell on the technologically transformed territory and lower courses of the river within the boundaries of the agrarian area. The change of the species composition of microorganisms is known to indicate the level of transformation of a hydro ecosystem on the whole (Harnisz et al., 2015). Bearing in mind that enterobacteria constituted the central part of the microbiocenosis of the river and were distinguished by a broad species spectrum, we conducted a quantitative assessment of the microorganisms' domination level. Analyzing the species ratio of isolated microorganisms from natural waters, the most common bacteria were *Escherichia* species, which were found almost along the entire length of the river and dominated the quantitative ratio in the technogenically transformed area (64.2%) and the urbanized area (59.2%) (Fig. 2).

However, microorganisms of the genus *Klebsiella* (17.2%) also reached moderately high values in the urbanized territory, while high titers of *Citrobacter* (47.1%) were recorded in the agricultural area.

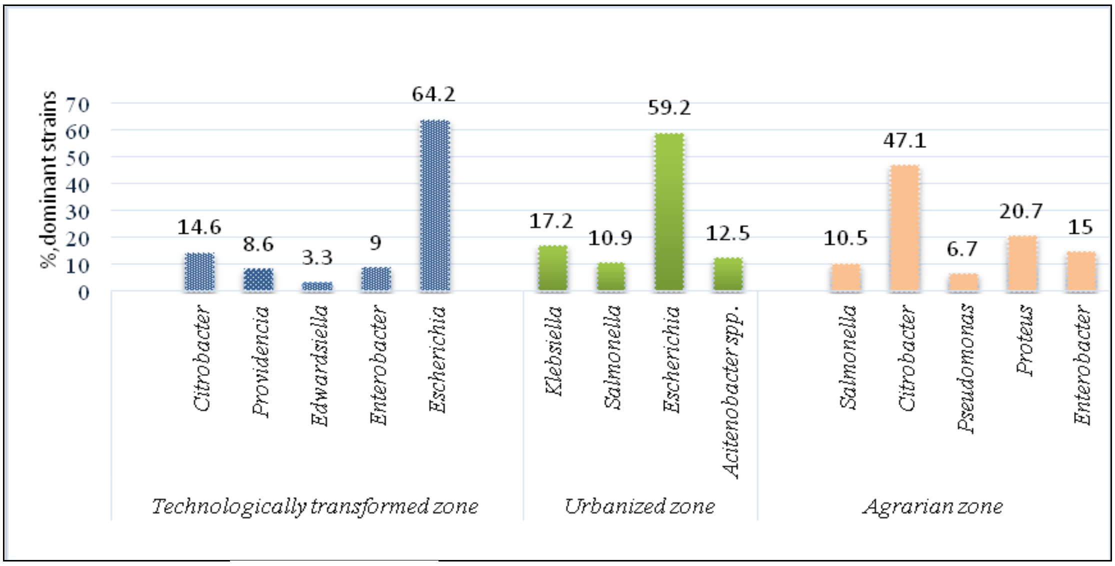

Figure 2: The predominant microorganisms isolated from Uzh River water.

Antibiotic resistance analysis of the most common microorganisms isolated from river water samples

The most commonly used strains were chosen for determining antibiotic susceptibility tests; they were selected and differentiated by investigation points. In the area of technologically transformed area such genera were allocated: the city of Perechyn – *Escherehia* (n = 20), 100 m from the site where the Domoradzh Stream flows into the Uzh River *Escherichia* (n = 114), *Edwardsiella* (n = nine), *Citrobacter* (n = 39), *Enterobacter* (n = 24), downstream from the city of Perechyn – *Escherichia* (n = 37), *Providencia* (n = 23). In the urbanized area, namely the city of Uzhhorod – *Klebsiella* (n = 44), *Acitenobacter* spp. (n = 32) and beyond the city – *Escherichia* (n = 87) and *Salmonella* (n = 28). In the agrarian territory, such microorganisms were dominated: *Citrobacter* (n = 98), *Proteus* (n = 43) in the village of Storozhnitsa and beyond – *Salmonella* (n = 22), *Enterobacter* (n = 31), and *Pseudomonas* (n = 14).

The results of the studies are presented in figures 3-5.

According to figures 3-5, the highest degrees of resistance are observed technogenically transformed and agricultural areas. Resistance indices are growing downstream of the river with a marked increase outside the settlements and at the plant's wastewater discharge point. Outside the plant, there is a high level of resistance to beta-lactams and tetracyclines. Compared to other areas, the number of multi-resistant forms and resistance to carbapenems and "protected" antibiotics (ampicillin-sulbactam, cefoperazone-sulbactam) is growing. The area outside the plant is contaminated with heavy metals and nitrogen compounds, which may increase the antibiotic resistance level (Bilkey and Nikolaichuk, 2017; Bilkei and Kryvtsova, 2018). High concentrations of heavy metals contribute to the spread and accumulation of ARGs (Martins et al., 2014). Downstream of the river, within the city, there is a slightly higher degree of sensitivity to antibiotics than in anthropogenically loaded areas; however, the trend towards a relatively high level of resistance to tetracyclines and penicillins persists. It is more facilitated by the uncontrolled wastewater discharge into the river system. However, one of the reasons may include natural resistance developed under various environmental factors (Finley et al., 2013). In the agricultural area, in the lower reaches of the river, resistance to second-generation fluoroquinolones is growing, and resistance to antibiotics of natural origin (ampicillin, gentamicin, and tetracycline) remains invariably at high level. According to Guardabassi et al. (2000) research, resistance to quinolones and tetracyclines is really widespread for the microorganisms of natural waters. A low resistance percentage is typical for carbapenems (imipenem and carbapenem) and third-generation cephalosporins (ceftriaxone). Based on these results, the most significant transformation is standard for an antibiotic-resistant anthropogenically loaded area, where a high level of contamination is observed.

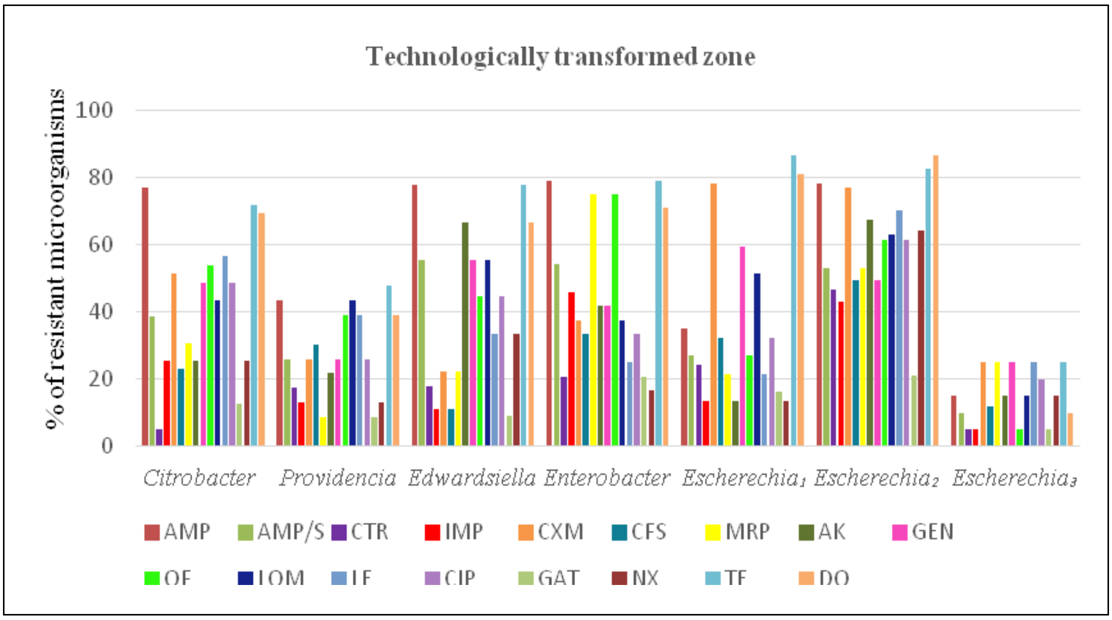

Figure 3: Antibiotic resistance of microorganisms isolated from technological territory, *Citrobacter*, *Edwardsiella*, *Enterobacter*, *Escherichia*[1] genera – outside the plant; *Providencia*, *Escherichia*[2] genera – outside the city Perechyn; *Escherichia*[3] genus – to the city Perechyn.

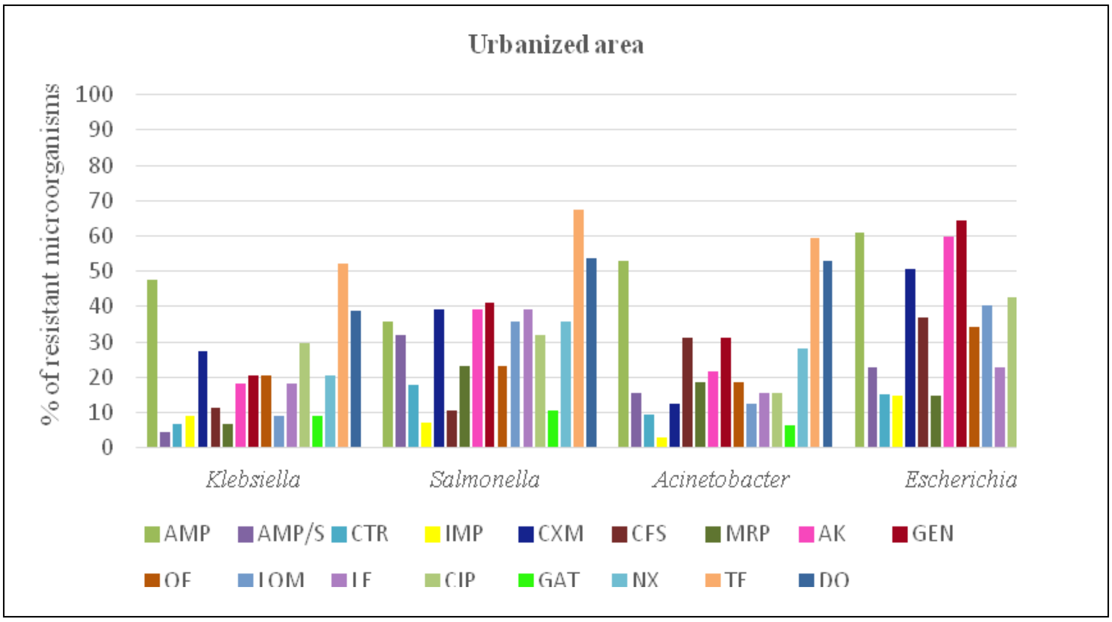

Figure 4: Antibiotic resistance of microorganisms isolated from the urbanized territory, *Klebsiella* and *Acinetobacter* spp. genera – to the city Uzhhorod; *Salmonella* and *Escherichia* genera – outside the city Uzhhorod.

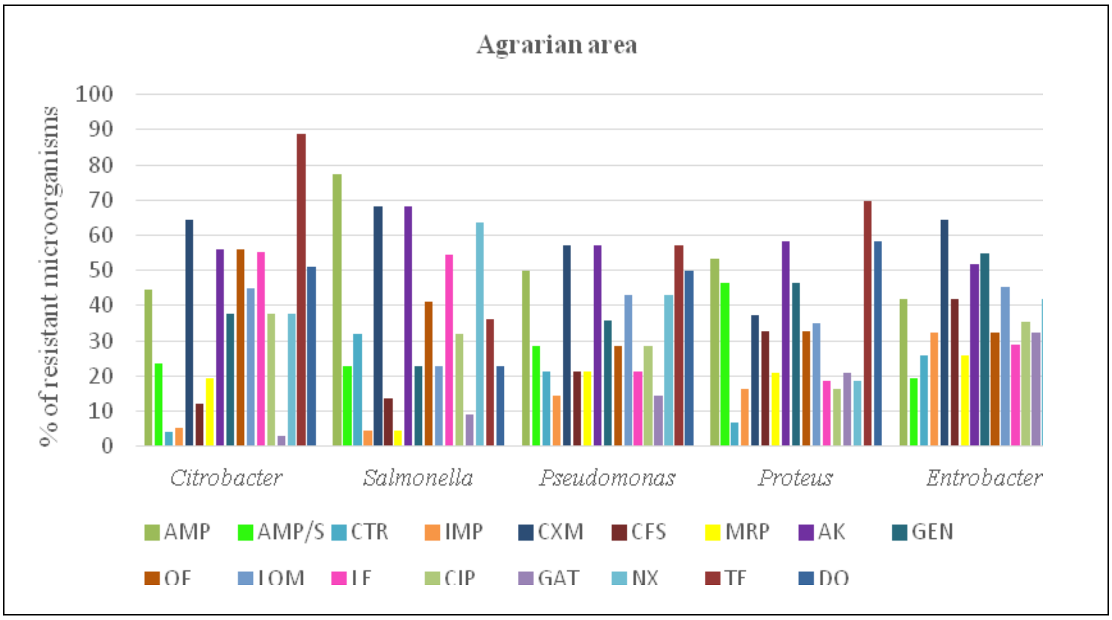

Figure 5: Antibiotic resistance of microorganisms isolated from the agrarian territory, *Citrobacter* and *Proteus* – to the village; *Salmonella*, *Pseudomonas*, and *Enterobacter* genera – outside the village.

Investigation of antibiotic resistance genes of isolated microorganisms

The results of the molecular genetic analysis made it possible to determine the presence of ARGs of isolated multiresistant microorganisms in the reservoir. To define the genetic determinants of resistance, we have selected multi-resistant gram-negative microorganisms that dominated the microbiome of the studied areas (Fig. 6).

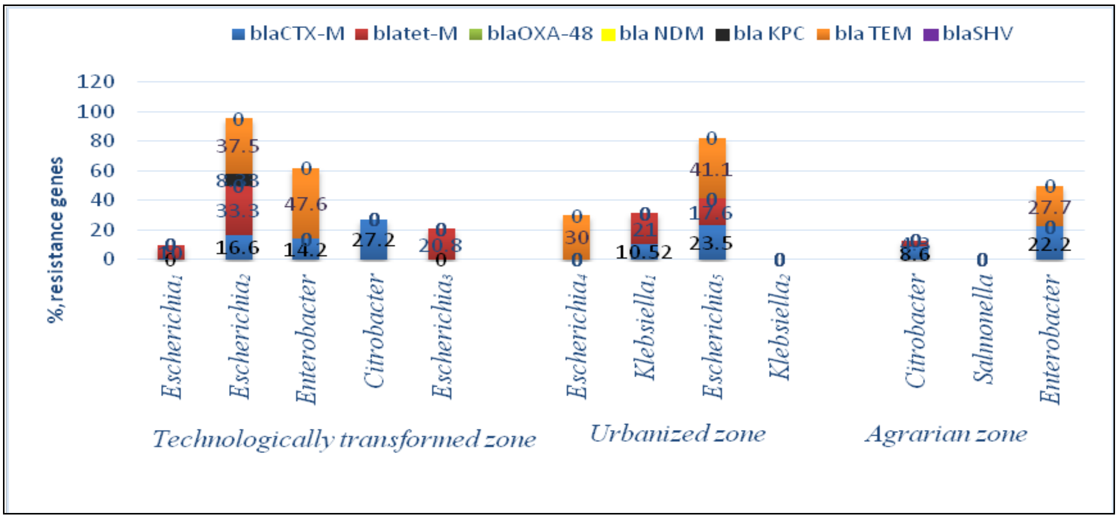

Figure 6: Genetic determinants of resistance of multidrug-resistance microorganisms isolated from the Uzh River, *Escherichia* – to the city Perechyn; *Escherichia*, *Enterobacter*, and *Citrobacter* – near the Domoradzh Stream, *Escherichia* – outside the city Perechyn; *Escherichia*, *Klebsiella* – to the city Uzhhorod; *Escherichia* and *Klebsiella* – outside the city Uzhhorod; *Salmonella* and *Enterobacter* – outside the village Storozhnytsia; *Citrobacter* – to the the village Storozhnytsia.

The presence of tetracyclines and b-lactamase resistance genes (bla_{TEM} and $bla_{CTX\text{-}M}$) were primarily identified in a group of strains of the genus *Escherichia* from the technogenically transformed territory. The results of the microbiological analysis also have shown a high level of phenotypic resistance to these groups of antibiotics among the identified microorganisms. In addition, genes encoding carbapenemases (bla_{KPC}) have been revealed in this area; these are less common in natural environments and are more dangerous since they provoke the gradual development of general resistance to drugs (Adegoke et al., 2020). At the same time, according to recent studies, carbapenem-resistant genes are increasingly found within the territory of Europe (Nordmann et al., 2011). A significant prevalence of ESBL genes such as bla_{TEM} and $bla_{CTX\text{-}M}$ has been observed in the urbanized area. The largest percentage of bla_{TEM} genes have been revealed among members of the genus *Escherichia.* According to the results of previous studies, bacteria of the genus *Escherichia* are characterized by a higher proportion of the spread of resistance (i.e. ESBL) in natural communities than other enterobacteria (Brolund and Sandegren, 2016). A likely source of resistance genes in a given area is municipal wastewater, which, as it is known, can act as reservoirs of resistant forms of microorganisms and genetic determinants of resistance, as well as a determining factor in the formation of environmental resistance (Karkman et al., 2019). A detrimental consequence of the significant proliferation of ESBL genes may be the development of various resistance mechanisms, including the ability to provide resistance to carbapenem due to further chromosome mutations of porine (Lutgring and Limbago, 2016). ESBLs have been identified on the territory exposed to the agricultural sector; the largest share of ESBLs falls on the $bla_{CTX\text{-}M}$ genes encoding quinolone resistance. The results of microbiological studies have also shown an increase in resistance to second- and third-generation fluoroquinolones in this area.

This study has revealed the appearance of more than one beta-lactamase in the same isolate; bla_{TEM} genes have been found both alone and in combination with $bla_{tet\text{-}M}$ genes. It indicates the evolution of microorganisms to antimicrobial resistance.

The results of the study showed a significant presence of ARGs in water samples. Thus, getting into the environment, ARGs may contribute new strains of microorganisms having drug resistance.

CONCLUSIONS

Nowadays, antibiotic resistance is one of the most severe threats to human health. The obtained results provide a basis to believe that the indicator of antibiotic resistance can be used as a marker of anthropogenic activity. One of the necessary practical implementations that need to be done is developing and applying the methods to quantify actual resistance genes in the aquatic systems. The next important direction will be to build a better separation of human and animal sources, including methods with clearly distinguished human and agricultural sources of resistance genes that will help develop strategies for reducing the effects of pollution. It is also really important to create and implement a monitoring system for antibiotic-resistant bacteria and their resistance genes in natural waters and on the way to different consumers. Although the problems of ARGs pollution have attracted some attention in recent years, there is still a need for more effort to reduce the possibility of ARGs entering and spreading into the environment.

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CLADOCERA FROM THE SEDIMENT OF HIGH ARCTIC LAKE IN SVALBARD (NORWAY)

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KEYWORDS: *Chydorus sphaericus* group, *Daphnia pulex*, Ephippia, Ny-Alesund, High Arctic.

ABSTRACT

The High Arctic Region's freshwater ecosystems serve as hot spots to study the impact of extreme warming conditions on the biota. The cladoceran remains have been recovered from the surface sediments of a non-marine water body near Ny-Alesund, Svalbard, Norway. The cladoceran (crustaceans) belongs to the *Chydorus sphaericus* group Frey, 1980 and *Daphnia pulex* Leydig, 1860. The ecology of the species suggests that they lived in a well-developed ecosystem with Water Quality Class 3. This study has implications for understanding the response of the present-day biota experiencing the changing climate conditions and using these remains for assessing palaeoenvironmental conditions.

ZUSAMMENFASSUNG: Cladocera aus den Sedimenten des Hocharktischen See auf Svalbard (Norwegen).

Die terrestrischen aquatischen Ökosysteme der Hocharktis dienen als Brennpunkte, um die Auswirkungen drastischer Erwärmungsbedingungen auf die Biota zu untersuchen. Die Cladocera-Überreste wurden aus den Oberflächensedimenten eines terrestrischen Gewässers in der Nähe der Siedlung Ny-Alesund, Svalbard, Norwegen, geborgen. Das Cladoceren (Krebstiere), auch Wasserflöhe genannt, gehören zur *Chydorus sphaericus*-Gruppe Frey 1980 und zur *Daphnia pulex* Leydig 1860. Die Ökologie der Arten legt nahe, dass sie in einem gut entwickelten Ökosystem mit Wasserqualitätsklasse 3 lebten. Diese Studie hat Auswirkungen auf das Verständnis der Reaktion der heutigen Biota, die sich ändernden Klimabedingungen erleben und diese Überbleibsel für die Bewertung der paläoökologischen Bedingungen verwendet werden.

REZUMAT: Cladocera din sedimentele unui lac din Arctica superioară din Svalbard (Norvegia).

Ecosistemele acvatice terestre din regiunea arctică superioară servesc drept hot spoturi pentru a studia impactul condițiilor de încălzire drastică asupra biotei. Rămășițele de cladocere au fost recuperate din sedimentele de suprafață ale unui corp de apă din apropierea așezării Ny-Alesund, Svalbard, Norvegia. Cladocerele (crustaceii) aparțin grupului *Chydorus sphaericus* Frey, 1980 și *Daphnia pulex* Leydig, 1860. Ecologia speciei sugerează că au trăit într-un ecosistem bine dezvoltat, cu clasa de calitate a apei 3. Acest studiu are implicații în înțelegerea răspunsului biotei actuale care se confruntă cu condițiile climatice în schimbare și în folosirea acestor rămășițe pentru evaluarea condițiilor paleoambientale.

INTRODUCTION

In general unexpected, the high northern latitude regions are experiencing drastic changes due to significant rising temperature related to the recent climate changes. The temperature rise in the High Arctic is double compared to the other regions of the world. This temperature rise is adversely affecting the Arctic ecosystems. (Dimante-Deimantovica et al., 2015) These regions have lower ecological diversity than tropical and temperate climate zones (Treut et al., 2007). The surface water biota inhabiting the ponds and lakes of the High Arctic region is affected by the high latitude region's stresses like high 24-hour daylight during the summer and complete darkness of the winter months. The study of the biota of the terrestrial and aquatic ecosystems is crucial to understanding the impact on the biota of climate warming conditions.

The small aquatic habitats experience the high northern latitude’s physical stresses in the form of increased ultraviolet radiation, complete darkness, desiccation, extended summer conditions, and increasing winter temperature. There had been an increase in these stresses’ intensity due to rapid climate warming (Dimante-Deimantovica et al., 2018). The microorganisms that dwell in these habitats are directly affected by environmental fluctuations. These organisms respond to changing environmental conditions and provide the important signature of the resulting biotic response. The observation and documentation of the biota are thus crucial. (Kling et al., 1992)

The biotic remains of the living organisms are preserved in the sediments after death. The study of these remains serves as an essential tool for reconstructing the palaeolimnological and paleoenvironmental conditions. Consumers' microscopic organic remains like small crustacean, Cladocera can be used to study the impact of warming on surface water ecosystems (Korhola and Rautio, 2001). Cladocera is a microscopic crustacean with a chitinous exoskeleton that is considered resistant to decay and preserved to provide a sedimentary record (Korhola and Rautio, 2001). The preserved remains of Cladocera are primarily derived from the chitinous exoskeleton and ephippia. Chitin has high preservation potential and is thus capable of providing a fossil record. The shell remains of *Chydorus* Leach, 1816 show varied surface structures that help to distinguish between different forms of the species complex. Their body is enclosed in a shell known as a carapace. The head is on the anterior side and is not covered by the carapace. The carapace is either smooth-walled or could have a surface with patterns of striae, polygons, etc. The body parts are broken down after the death of the Cladocera, and the hard chitinous parts get preserved in the sediments under suitable conditions. The commonly preserved parts are head shields and carapaces that can be used to identify Cladoceran forms (Korhola and Rautio, 2001). *Chydorus* Leach, 1816 is the type genus of the family Chydoridae Dybowski and Grochowski, 1894 and prefers the littoral habitat of freshwaters (Kotov et al., 2016). In *Daphnia*, paired eggs are enclosed within the ephippia, which has multiple protective layers to provide a better chance of survival to the offspring (Korhola and Rautio, 2001).

The climate of the Svalbard archipelago area of Norway is in a characteristic High Arctic climate. About two-thirds of the land area of Svalbard is covered by ice. The studied lake is situated near Ny-Alesund (78°55’N, 11°56’E). Ny-Alesund is inhabited by the international research community analysing varied aspects. The climate of Ny-Alesund is mild compared to eastern Svalbard because of the influence of the Warm Spitsbergen Current on the west coast. The coastal areas are ice-free and are occupied by surface water habitats. The estimated average temperature of Svalbard land areas is –8.7°C. A mean annual temperature rise of about 2.5°C has been observed on Svalbard in the past 100 years (Dimante-Deimantovica et al., 2018).

The surface water ecosystems of Svalbard have been sporadically studied, but due to its isolated location, the studies are fragmentary and inconsistent (Dimante-Deimantovica et al., 2018). This has led to a gap in the surface water microscopic flora and fauna record at this extremely sensitive high in the Arctic Archipelago, witnessing drastic changes due to rising temperature. It is essential to have many consistent and regular studies of the sensitive aquatic ecosystem and its components to generate essential and crucial baseline data. This will help understand the behaviour of the High Arctic surface water ecosystems under the current scenario of changing climate, but it will also help mitigate the harmful impacts that will be beneficial for carrying out palaeoecological and paleoenvironmental studies.

Usually, paleo-reconstructions of the environment are based on the ecological preferences of the organisms identified. Unfortunately, for invertebrates, this information is minimal. We have only four works where the values of the saprobity indices of some invertebrate species are mentioned and the corresponding zones of water self-purification (Yermolaeva and Dvurechenskaya, 2013, 2016; Derevenskaya, 2015; Golubkov et al., 2017). Thus, we have some data on organisms-indicators of water quality (Barinova, 2017a, b), which are used to understand the properties of studied lake's paleoenvironment in the Svalbard Archipelago.

This study aims to reveal the invertebrate species in sediments of the lake and characterize the paleoenvironment by bioindication.

MATERIAL AND METHODS

Description of the study site

The bottom sediment was collected from the studied lake, located on the west coast of Ny-Alesund, Svalbard, Norway, 78°56'N, 11°49'E.

The studied small lake has an average depth of about one meter, and pH of water is about 8.3 during the summer season. The lake is situated relatively far from the glacier towards the Kongsfjorden and is about two km away from the human settlement of Ny-Alesund across the river Bayelva (Fig. 1). A glacial does not feed the lake and is occasionally visited by birds.

Sampling and laboratory study

The dry sediment sample (5 g) was processed following the standard procedure for organic matter extraction. The method involves using 35% cold hydrochloric acid (HCl) for the removal of carbonate content, followed by treatment with 30% hydrofluoric acid (HF). Acid was removed by washing with deionised water after the treatment with HCl and HF. The recovered organic matter was sieved using 20-micron mesh. Slides were mounted using glycerine jelly and were studied under the Leitz Laborlux D microscope at 400x and 1000x.

The biological material identification was made based on Szeroczynska and Sarmaja-Korjonen (2007).

The microscope slides of the studied material were deposited in the museum of the Birbal Sahni Institute of Palaeosciences, Lucknow vide statement no. BSIP-1556.

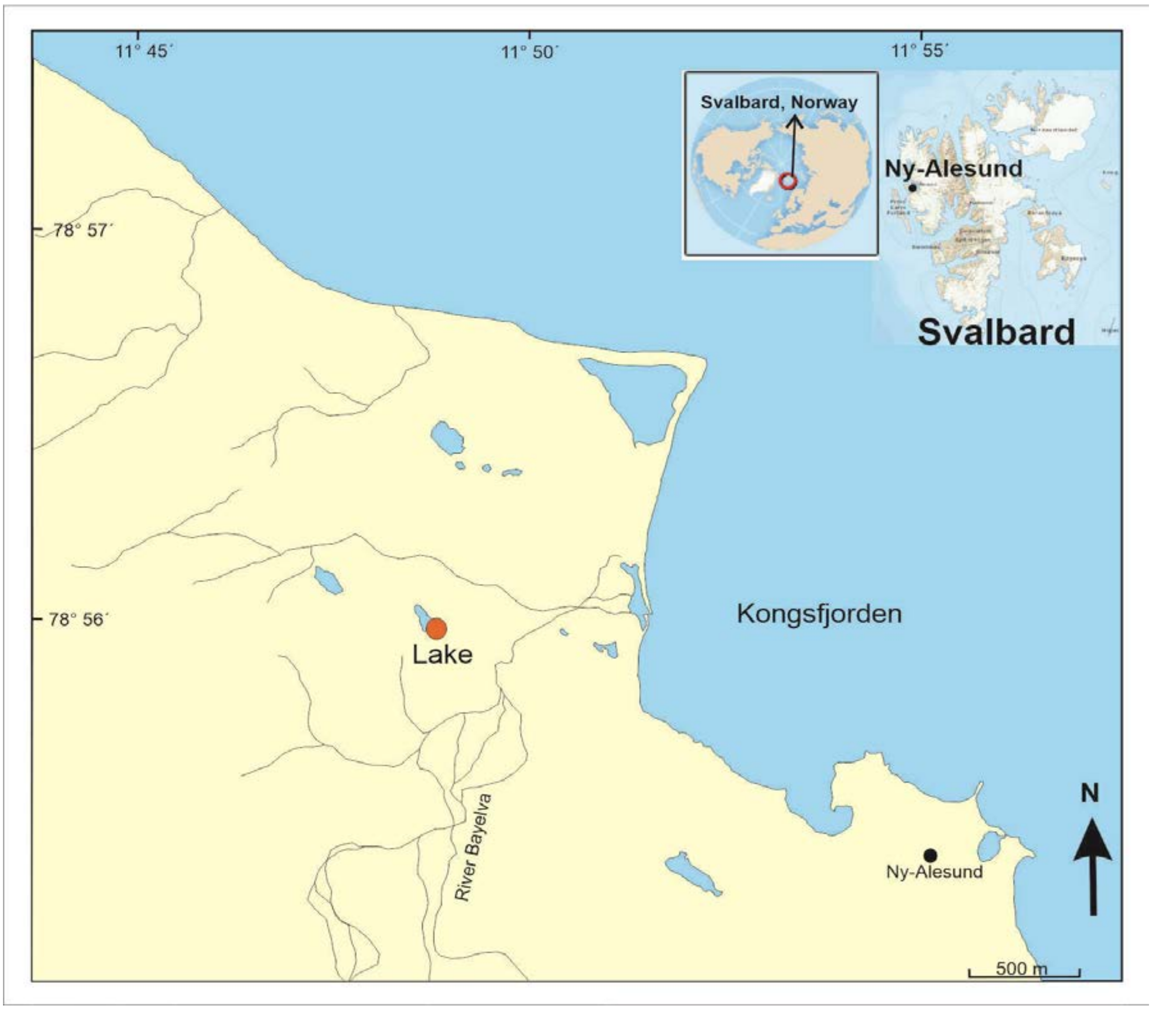

Figure 1: Map of the study area. The red circle is Svalbard, Norway, on the world map. Inset image of the map of Svalbard shows the location of Ny-Alesund marked by a black dot. Map of the study area Ny-Alesund shows the position of the studied lake marked with a red dot.

RESULTS AND DISCUSSION

The acid-resistant remains of the invertebrate Cladocera have been recovered from the sediments. The Order Cladocera of the Class Branchiopoda is represented by a group of microscopic crustaceans that inhabit all the surface water ecosystems. The fossil record of cladoceran dates back to the Jurassic period when the ancestor crustaceans were present in the sea during the time of the Supercontinent Pangea (Smirnov, 1971). The modern cladocerans mainly occupy the surface water habitats in freshwater to brackish and have only a few marine forms. They form an essential part of the aquatic ecosystem as consumers who graze on algae and other heterotrophs. Cladocerans are important contributors to the regeneration of nutrients; they also serve as food for other planktons and fishes. The Cladocerans have a chitinous exoskeleton. Even though chitin has relatively high preservability, it is also prone to degradation. This affects the overall preservation potential of chitinous cladocerans (Rautio, 2000). The chitinous exoskeleton formed of more hydrous chitinous polymers are better preserved and well represented in the sedimentary record (Deevey, 1964).

A detailed study of the Holarctic *Chydorus sphaericus* (Müller, 1776) complex based on the molecular markers led to the finding of seven related taxa in the *C. sphaericus-brevilabris* complex Belyaeva and Taylor, 2009 in the Holarctic, which also includes *C. biovatus* Frey, 1985 (Belyaeva and Taylor, 2009). The recovered remains belong to the Cladocera, *C. sphaericus* group and *Daphnia pulex* (Müller, 1776). The remains are shell fragments of *C. sphaericus* group and ephippia of *D. pulex* (Fig. 2).

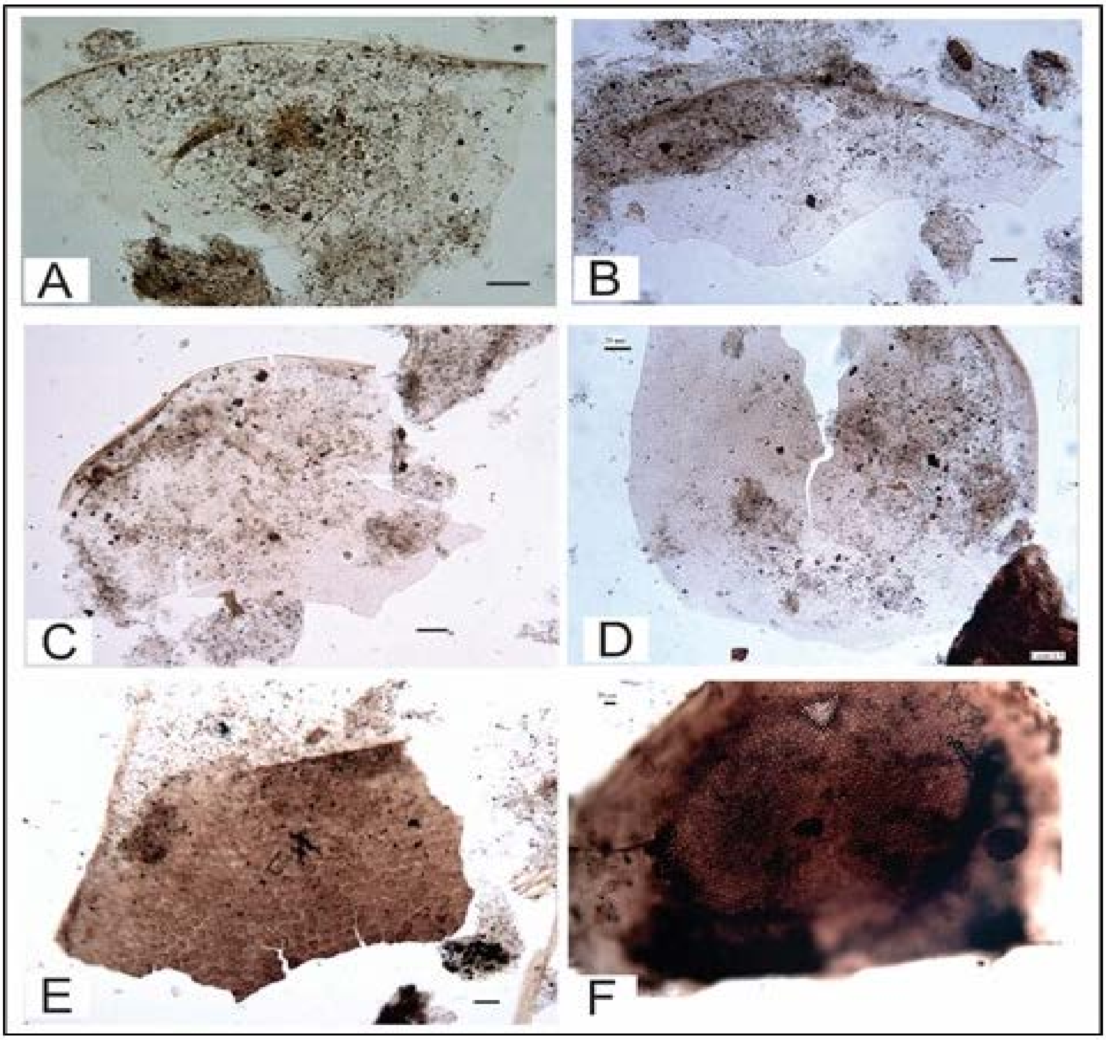

Figure 2: A-E, *Chydorus sphaericus* group remains (A, EFP O52/1), (B, EFP S26/1), (C, EFP K54/4), (D, EFP M35/3), (E, EFP V39//1), F – *Daphnia pulex* ephippia (F, EFP M54/2), BSIP Slide Number 16258, EFP – England finder position; scale bar: 20µm.

The recovered disarticulate shell fragments of this group display different sculpturing patterns of the surface. In some, the shell reticulation is in the form of polygons spread all over the surface in a spider web-like pattern, and the polygons have punctuated to smooth surface in different forms. The polygons' boundaries vary from straight (*C. gibbus* Sars, 1890) to wavy (*C. biovatus*). In some forms, the shape of the polygons is distinct, as in *C. brevilabris* Frey, 1980, in which the polygons are elongated in the series present on the posterior margin of the shell. The shell surface reticulation of *C. gibbus* is in the form of polygons that are spread all over the surface in a spider web-like pattern. The polygons have fine punctae scattered on the surface. The ephippia of daphnia contain paired eggs enclosed within several protective layers. It helps protect against desiccation, temperature fluctuations, and degradation (Korhola and Rautio, 2001). The Cladocerans have been studied previously from the water and surface sediments of the lakes in the Hornsund region of Svalbard. It was noted that more Cladocera were recovered from water as compared to sediments (Zawisza and Szeroczyńska, 2011). *Chydorus* has been recovered only from lake surface sediments.

The database on the ecology of aquatic organisms, compiled at the Institute of Evolution of the University of Haifa (Barinova, 2017a; Barinova et al., 2019), was used to reconstruct the conditions in which the remains of *Daphnia* and *Chydorus* that we found lived. In particular, for the identified taxa, the calculated saprobity indices S and self-purification zones related to many water quality variables ranges for communities of continental water bodies are known (Yermolaeva and Dvurechenskaya, 2013, 2016; Derevenskaya, 2015; Golubkov et al., 2017). The species-specific index S for *C. sphaericus* fluctuated in the range of 1.28-2.00 (Yermolaeva and Dvurechenskaya, 2013, 2016; Derevenskaya, 2015; Golubkov et al., 2017) that correspond to Classes 2-3 of water quality (Barinova, 2017b). On the contrary, *D. pulex* has a more broad tolerance to organic pollution, with index S in the range 1.72-2.80 (Yermolaeva and Dvurechenskaya, 2013, 2016; Derevenskaya, 2015), which corresponds to Classes 3-4 of Water Quality. Self-purification zones for both species were also notably overlapped. So, *C. sphaericus* prefer a community with beta- to oligo-betamesosaprobic indicators (Barinova, 2017a). At the same time, *D. pulex* inhabits more organically polluted waters where alphamesosaprobes flourish. We tried to assess the lake water pollution with the invertebrates` ecology. Still, earlier it has been revealed that they give a slightly higher water pollution state than autotrophs (Protasov et al., 2019). Water quality in the studied lake can be about Class 3.

CONCLUSIONS

The study provides an account of the Cladocera genus, *C. sphaericus* group and *Daphnia pulex* from the surface sediment of a coastal lake of Ny-Alesund, Svalbard. The study serves as a preliminary record to conduct more research on the species' ecological preferences inhabiting the lake. The recovered species' known ecology may indicate that they would have been living in the well-developed ecosystem, inhabited by oligo-beta- to alpha-mesosaprobic species of producers and consumers in fresh waters having low to middle enrichment of dissolved organic, of Class 3 of water quality with a high level of self-purification. This initial study of the organic-walled remains of microzooplankton remains made up of chitin would provide direction for more detailed investigations of the biota of surface water ecosystems experiencing severe warming conditions at High Arctic sites. The same could be extended back in time to understand the past climate fluctuations and biotic responses.

Bottom sediments of Arctic lakes capture the picture of the ecosystem that developed in previous periods of its development. Information on the taxonomic composition and ecology of organisms can be compared with modern ones, which makes it possible to trace the direction of changes in the ecosystem during the period of climate change. Thus, we can look at the ecosystem of the Arctic lake as a chronicle of the biota's response to environmental change in order to understand past climate fluctuations and biotic responses.

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HISTOLOGICAL STUDY OF THE IMMUNE SYSTEM IN ZEBRAFISH, *DANIO RERIO* (HAMILTON, 1822)

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KEYWORDS: Zebrafish, histology, immune system.

ABSTRACT

The aim of the present study was to investigate the cellular characteristics of the immune tissues of Zebrafish, *Danio rerio* (Hamilton, 1822). The fish were fixed in Bouin's solution for 24 hours then dehydrated, cleared, paraffinized, embedded and finally sectioned, stained and observed through optical microscopy. Results showed that immune system tissues of Zebrafish include the apical part of the kidney, thymus, and spleen. The apical part of the kidney was composed of hematopoietic tissue containing blood and immune cells. The spleen was a single organ located at the abdominal cavity containing melanomacrophages. The thymus was observed as a paired organ at the posterior part of the branchial cavity. Results showed that the immune system of the Zebrafish was dispersed in several organs of the body and that this species could be used as a laboratory model organism in immune system studies.

RÉSUMÉ: Étude histologique du système immunitaire chez Zebrafish, *Danio rerio* (Hamilton, 1822).

Le but de la présente étude était d'étudier les caractéristiques cellulaires des tissus immunitaires du poisson zèbre, *Danio rerio* (Hamilton, 1822). Les poissons ont été fixés dans la solution de Bouin pendant 24 h puis déshydratés, clarifiés, paraffinés, inclus et finalement sectionnés et colorés et observés par microscopie optique. Les résultats ont montré que les tissus du système immunitaire du poisson zèbre comprenaient le rein de la tête, le thymus et la rate. Le rein de la tête était composé de tissu hématopoïétique contenant du sang et des cellules immunitaires. La rate était un organe unique situé dans la cavité abdominale contenant des mélano macrophages. Le thymus a été observé comme un organe apparié à la partie postérieure de la cavité branchiale. Les résultats ont montré que le système immunitaire du poisson zèbre était dispersé dans plusieurs organes du corps et que cette espèce pourrait être utilisée comme organisme modèle de laboratoire dans les études du système immunitaire.

REZUMAT: Studiu histologic al sistemului imunitar la peştele zebră, *Danio rerio* (Hamilton, 1822).

Scopul prezentului studiu a fost de a investiga caracteristicile celulare ale țesuturilor imune ale peștelui zebră, *Danio rerio* (Hamilton, 1822). Peștii au fost fixați în soluție Bouin timp de 24 de ore, apoi au fost deshidratați, curățați, parafinizați, încorporați și, în final, secționați, colorați și observați cu ajutorul microscopiei optice. Rezultatele au arătat că țesuturile sistemului imunitar ale peștilor zebră includ rinichiul anterior, timusul și splina. Capul rinichiului a fost compus din țesut hematopoietic conţinând sânge și celule imune. Splina a fost singurul organ situat la nivelul cavității abdominale conținând melanomacrofage. Timusul a fost observat ca un organ pereche în partea posterioară a cavității branhiale. Rezultatele au arătat că sistemul imunitar al peștilor zebră este dispersat în mai multe organe ale corpului și această specie ar putea fi folosită ca model de laborator în studiile sistemului imunitar.

INTRODUCTION

The study and research of the immune system of aquatic organisms, including fish, leading biologists with the drive to understand the immune system process in fish which will help prevent and control aquatic diseases, especially those affecting ornamental and high economic value fish. These fish make up a large part of the fish trade. Ornamental fish are also of great importance to biologists because of their small size and usefulness in understanding the immune system of fish. The study of fish defence mechanisms and how the immune system works can be very effective in preventing, treating, and controlling aquatic diseases. Studying and recognizing the immune systems in a variety of fish can also lead to a reduction in the use of antibiotics in aquatic organisms, thus greatly reducing the side effects of these compounds on the human body and the environment. (Ghalambor et al., 2020)

Fish were the first vertebrates to possess both an innate and acquired immune system in the evolutionary pathway. Multiple studies have been conducted on the fish's immune system, showing that it is rather simple compared to higher vertebrates. The spleen, thymus, and kidney are regarded as being the major immune organs in fishes, albeit with slightly various roles between species. (Nasrullah et al., 2019)

Fish lymphoid organs are consistent with the thymus, apical part of the kidney, and spleen. Just after fertilization, lymphoid organs start their evolution in fish. A fish's innate immune system consists of physical barriers such as the skin epithelium, gills, mucosal layers, immune cells such as macrophages, granulocytes, natural killer cells, and soluble components such as lysozyme, agglutinins, perceptins (lectins and opsonins), anti-bacterial agents, and transporters (iron-binding proteins). In addition, the complement system and interferons are responsible for acquired immunity. (Salinas et al., 2011)

The Zebrafish, *Danio rerio,* has become an interesting biological model for safety analysis. This fish has many advantages over other biological models, including ease of testing, ease of prescribing drugs, and its fertility. Zebrafish is an exceptional laboratory model on which genetic studies have been used to identify or treat some human diseases. (Khoshnood, 2015)

The Zebrafish is a small, low-cost species with a high level of morphological, physiological and genetic coordination with the human genome. Modeling the human condition in Zebrafish makes it possible to discover potential therapeutic targets and their molecular conflicts. Therefore, in the present study, the cellular characteristics of the immune system tissues of this fish were investigated.

MATERIAL AND METHODS

Fish

Zebrafish, *Danio rerio* (2.3-3 cm total body length) was purchased from an ornamental fish breeding center in Dezful, Khuzestan, Iran, and transported to the laboratory in plastic bags containing aerated fresh water. The fish were anesthetized and sacrificed with a solution of clove powder, then immediately transferred to storage solutions for the next steps.

Histology

For the histological study, 10 fish were euthanized and the whole body was immediately immersed into Bouin's fixative for 24 h, rinsed, and dehydrated in an ascending series of ethanol, followed by butanol and xylene for embedding in paraffin (Merck). Following embedment in paraffin, transversal, and longitudinal sections of six μm were cut on a Leica RM2255 microtome and collected on glass slides consecutively (all sections were collected) and stained with hematoxylin and eosin (Khoshnood, 2015, 2017).

RESULTS AND DISCUSSION

Histological study of Zebrafish showed that the tissues involved in the immune system of this fish include the apical part of the kidney, thymus, and spleen. The results showed that the kidney is composed of two parts: the apical part of the kidney and trunk. The apical part of the kidney is clearly composed of hematopoietic tissue and the trunk portion consists of glomeruli and renal tubules. In the hematopoietic section of the apical part of the kidney, melanoma macrophages were visible along with other blood cells being produced. Melanoma macrophages were phagocytic cells containing various pigments such as melanin (brown-black) that were observed in the hematopoietic tissue of the apical part of the kidney (Fig. 1).

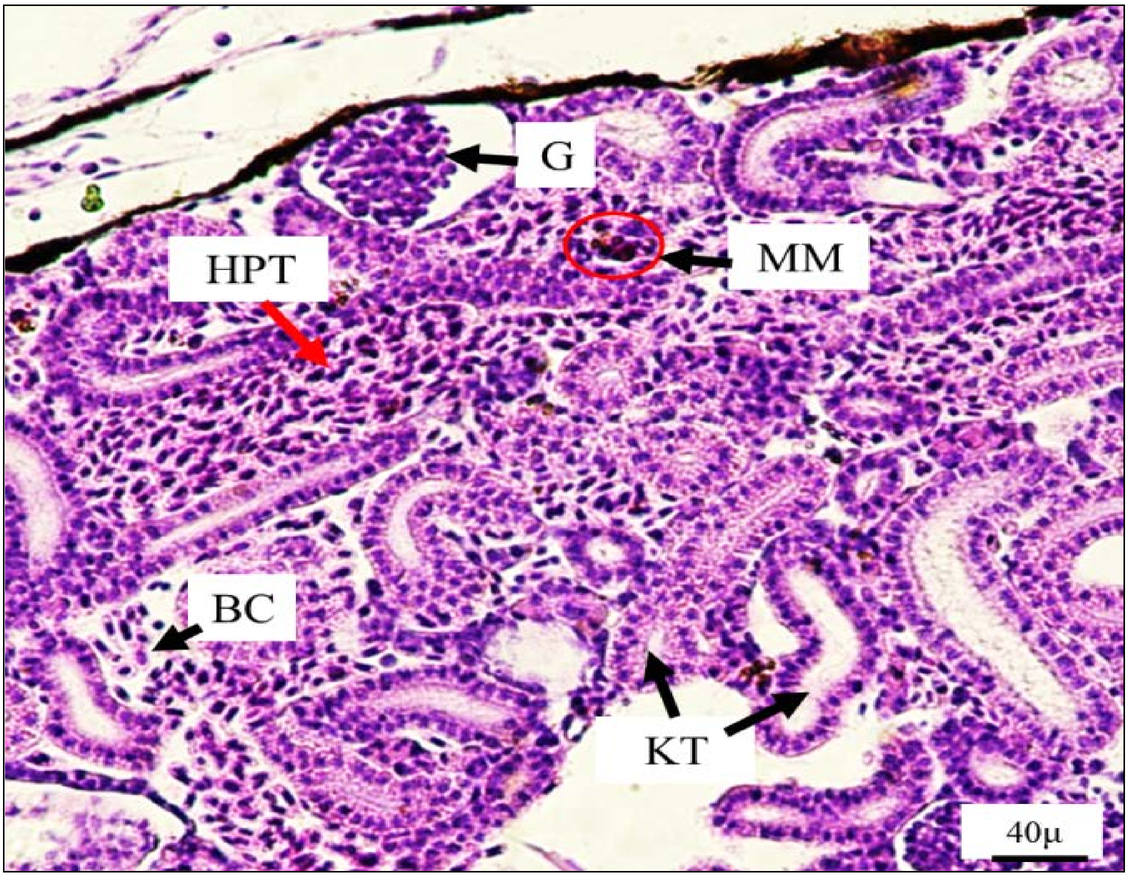

Figure 1: Histology of the apical part of the kidney in Zebrafish, *Danio rerio*, which consists of hematopoietic tissue and renal tubules. Items seen in the image: HPT: Hematopoietic Tissue; G: Glomeruli; MM: Melano-Macrophage; BC: Blood Cell; KT: Kidney Tubule.

The spleen was a single organ in the abdominal area attached to the gastrointestinal tract. Blood vessels, white pulp and red pulp were observed in the spleen tissue. The limb was covered by a thin capsule of connective tissue. The red pulp contained a large portion of the spleen, including sinusoids and blood cells, and formed the bulk of splenic tissue. The white pulp was composed mainly of lymphocytes that had accumulated around the blood vessels (Fig. 2).

The thymus was observed as a pair of organs in the posterior part of the gill cavity. Epithelial-like cells formed the thymus parenchyma that provided a scaffold for thymocytes. Two regions of the cortex, including thymocytes and the medulla (central part), which were composed mostly of epithelial cells, were observed (Fig. 3).

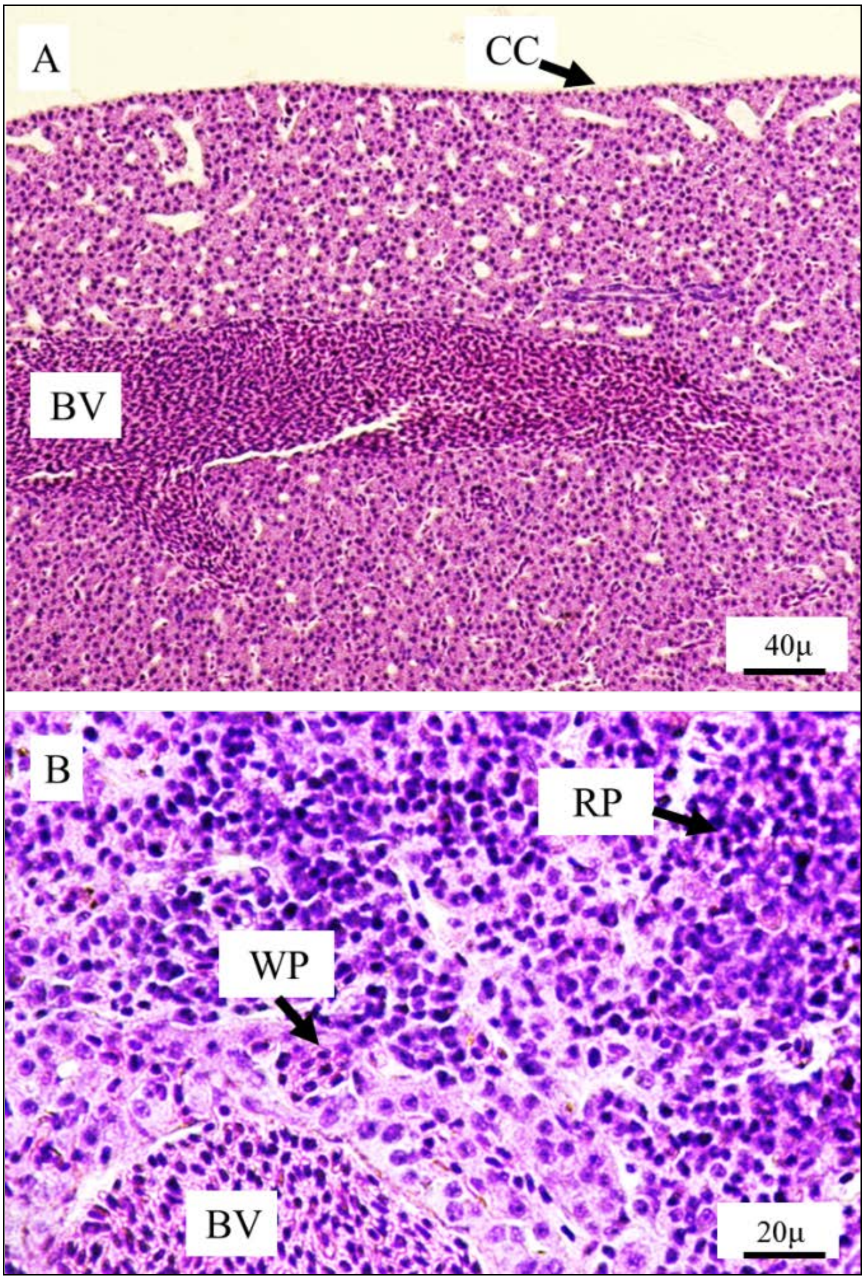

Figure 2: Histology of the spleen in Zebrafish, *Danio rerio*. Section A: longitudinal section of the spleen in which blood vessel (BV) and connective tissue capsule (CC) are visible. Section B: enlargement of spleen tissue with white pulp (WP – pink), red pulp (RP – purple) and blood vessels (BV). Items seen in the image include: connective tissue capsule (CC); white pulp (WP); red pulp (RP); blood vessel (BV).

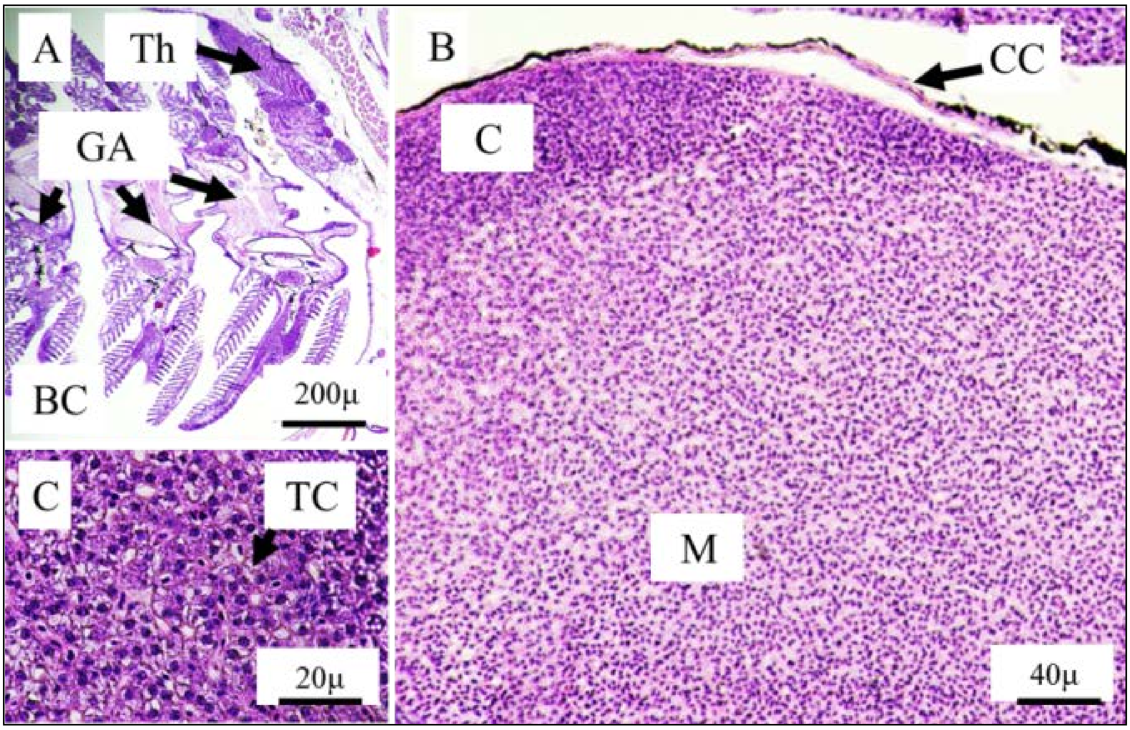

Figure 3: Histology of the thymus in the Zebrafish, *Danio rerio*.
Section A: position of thymus tissue in the dorsal part of the gill cavity. Section B: two sections of cortex (C) and medulla (M) are seen along with connective tissue capsules. Section C: a close-up of the thymocytes (TC) cells that make up thymus tissue. Items seen in the image include: connective tissue capsule (CC); thymus (Th); gill arch (GA); branchial cavity (BC); cortex (C); medulla (M); thymocyte (TC).

The fish immune system consists of innate as well as acquired responses, both of which protect against pathogens. Immune responses are also divided into two groups: cellular and humoral. Various factors, including lymphocytes, macrophages, neutrophils, cytokines, immunoglobulin, and the complement system, play a role in these responses. Since fish immune system responses rely primarily on innate immunity, macrophages play the most important role in this system (Nayak, 2010). In addition to the role of these cells in the production of cytokines, macrophages are responsible for phagocytosis and the killing of invasive and foreign cells (Boshra et al., 2006). The results of the present study showed that the immune system of Zebrafish, *Danio rerio*, as an ornamental freshwater fish, consisted of the thymus, spleen, and apical part of the kidney. Various studies have shown that the most important organs and tissues involved in the immune system of fish include the thymus, spleen, and kidneys (Bowden et al., 2005).

Previous studies have shown that the spleen is responsible for purifying the blood of old and worn out blood cells, especially red blood cells. This activity takes place mainly in the red pulp of the spleen. White pulp, on the other hand, is a site of accumulation of lymphoblasts, lymphocytes, macrophages, platelets, adult and immature neutrophils, and eosinophils, which are well described in striped bass (Hanington et al., 2009).

The liver is generally covered by a thin connective tissue capsule that has protractions to the liver tissue. Liver lobules are not distinctive and enclosed areas, which is generally dependent on the fish species. (Khoshnood, 2017)

The thymus, kidney, and the spleen are the largest lymphoid organs in fish. Thymic structure, in contrast to the higher vertebrates, is highly variable and also in multiple species, it is not easy to clearly distinct between the cortex and the medulla. The apical part of the kidney in fish has the same role of bone marrow in higher vertebrates and is the main site of hematopoiesis. The main immune cells found in the apical part of the kidney are macrophages, which aggregate into so-called melanomacrophage centers and lymphoid cells especially the B cells, which are found at all developmental stages (Rodrigues et al., 2020).

All organisms have defence mechanisms against pathogens and free radicals. Among these defence mechanisms are antioxidant enzymes that remove oxidative stress products such as free radicals and reactive oxygen species. Any disturbance in these defence systems can upset the balance of the living body. Catalase and superoxide dismutase enzymes are among the most important antioxidant enzymes. The first defence barrier for aquatic organisms under stressful conditions are antioxidant enzymes, the study of which can lead to a better understanding of the immune system's defence processes. Lysozyme is present in many vertebrates and is mainly produced by white blood cells. Lysozyme has been studied in mucus secretions, renal gill spleen, serum and the gastrointestinal tract of various organisms. Lysozyme, along with TNFα, plays an important role in fish immune responses (Ghalambor et al., 2020). Previous studies have shown that lysozyme is secreted by white blood cells and is found in mucus, gills, kidney, spleen, gastrointestinal, and serum secretions and can break the glycosidic bonds of the peptidoglycan layer of gram-positive bacteria (Nayak, 2010).

CONCLUSIONS

The results of the present study showed that zebrafish, *Danio rerio*, had a complete immune system consisting of the main immune organs of the spleen, thymus, and apex of the kidney. This shows that zebrafish have protection against pathogens and destructive factors. The results also showed that the immune system of this fish species is scattered in different organs of the body and the pattern of this distribution and the structure of these tissues involved in the immune system is similar to other bony fish.

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EPIZOOTIC ULCERATIVE SYNDROME (EUS) FISH DISEASE CHRONOLOGY, STATUS AND MAJOR OUTBREAKS IN THE WORLD

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KEYWORDS: wetlands, habitat, fish, Epizootic Ulcerative Syndrome.

ABSTRACT

Epizootic Ulcerative Syndrome (EUS) has been causing large-scale mortality among the freshwater fishes of the globe since the 1070s.

The symptoms include large haemorrhagic cutaneous ulcers, epidermal degeneration and necrosis followed by sloughing of scales. There have been many studies on EUS throughout the world. In India, since the initiation of EUS, in 1988, our study tried to reveal the aetiology of the disease through extensive and intensive studies on different aspects, like limnological, physical, chemical, bacteriological, fungal, viral including electron microscopic studies. Details of EUS investigation has been discussed in the present paper.

RÉSUMÉ: Syndrome ulcératif épizootique (SUE) chronologie des maladies des poissons, situation et principaux foyers dans le monde.

Le syndrome ulcératif épizootique (SUE) est à l'origine d'une mortalité à grande échelle chez les poissons d'eau douce du globe depuis les années 1070.

Les symptômes comprennent de grands ulcères cutanés hémorragiques, une dégénérescence et une nécrose de l'épiderme suivies d'une desquamation. De nombreuses études sur le SUE ont été réalisées dans le monde entier. En Inde, depuis le lancement du SUE, en 1988, notre étude a tenté de révéler l'étiologie de la maladie par des études approfondies et intensives sur différents aspects, comme les études limnologiques, physiques, chimiques, bactériologiques, fongiques, virales, y compris au microscope électronique. Les détails de l'enquête de l'EUS ont été abordés dans la présente travaux.

REZUMAT: Sindromul ulcerativ epizootic (EUS) cronologia bolii peştilor, starea și focarele majore din lume.

Sindromul ulcerativ epizootic (EUS) a provocat mortalitate pe scară largă în rândul peştilor de apă dulce de pe glob încă din anii 1070.

Simptomele includ ulcere cutanate hemoragice mari, degenerescență epidermică și necroză, urmate de pierderea solzilor. Au existat numeroase studii asupra EUS în întreaga lume. În India, de la apariţia EUS, în 1988, studiul nostru a încercat să dezvăluie etiologia bolii prin studii ample și intensive asupra diferitelor aspecte, cum ar fi limnologic, fizic, chimic, bacteriologic, fungic, viral, inclusiv studii microscopice electronice. Detaliile anchetei EUS au fost discutate în prezenta lucrare.

INTRODUCTION

The hitherto unknown virulent enigmatic EUS has been sweeping unabated, unhindered semi-globally causing large-scale mortality among the freshwater fishes (FW), causing fear psychosis among the fish eaters, leading to untold hardship to the fishermen and devastating the economy of some countries (Kar, 2015).

Following the report of mycotic granulomatosis (MG) in Japan in 1971 (Egusa and Masuda, 1971; Miyazaki and Egusa, 1972), the earliest reports of EUS could be traced from the red spot disease (RSD) in Australia, sometime in 1972 (Mckenzie and Hall, 1976; Callinan et al., 1989) and Papua New Guinea in 1974 (Coates et al.,1989), from where, EUS has been sweeping almost in a chronological manner through most of the South-East and South Asian countries, like Indonesia (1980), Malayasia (1979-1983) (Shariff and Law, 1980), Thailand (1985) (Tonguthai, 1985), Kampuchea and Lao (1984) (Lilley et al., 1992), Myanmar (1984-1985) (Soe, 1990); Sri Lanka (1987) (Costa and Wijeyarantne, 1989); Bangladesh (March, 1988) (Barua, 1994), until, EUS had reached India through the Barak Valley region of Assam during July, 1988, and, has been sweeping the region, even today, causing large-scale mortality among the freshwater fishes (Kar, 2007, 2013, 2015, 2019).

Thus, EUS had been reported from an increasing number of countries, where it had become quikly widespread in both cultured and wild fish populations (Blazer et al., 2002).

Likewise, ulcerative mycosis (UM), an ulcerative syndrome was reported in estuarine fish on the East Coast of the United States of America since the early 1980s. This had been ascribed to the same cause, according to some researchers (Blazer et al., 2002).

The pattern of spread to distinctly separate geographic locations within a relatively short period of time had been considered by some quarters as consistent with the progressive dissemination of a single infectious agent (Lilley et al., 1997; Baldock et al., 2005; Kar, 2007, 2010, 2013, 2015, 2019).

Initially, the syndrome was called by various names, like ulcerative disease syndrome (UDS), fish disease syndrome (FDS), etc. Finally, the name epizootic ulcerative syndrome (EUS), was adopted in 1986 at the meeting of the Experts Consultation Committee on Ulcerative Fish Diseases in Bangkok (FAO, 1986). Outbreaks of EUS have been often reported in a large number of countries in the Asia-Pacific region.

In India, widespread initiation of outbreak of EUS started from Barak Valley region of Assam since July, 1988 (Kar, 2015). Outbreaks of EUS in India have been comprehensively reviewed at various fora (The Zoological Society of Assam, 1988; Jhingran and Das, 1990; ICSF, 1992; Mohan and Shankar, 1994, etc.).

From Barak Valley region of Assam, EUS has been spreading and sweeping, almost unabated and more or less in a chronological manner through other regions of India, notably, West Bengal (1989), Bihar (1989), Odisha (1989), UP (1990), MP (1990), Maharastra (1991-1992), Karnataka (1993), Goa (1993), Tamil Nadu (1993), Andhra Pradesh (1992-1993), Kerala (1994-1995), till EUS had reached Pakistan during 1998-1999 and is said to be progressing further.

EUS is characterized by the occurrence of large haemorrhagic or necrotic ulcerative lesions on the bases of the fins and other parts of the body which becomes larger inflamed areas with acute degeneration of epidermal tissues (Kar, 2015).

Initiation of study on EUS and different affected species

The first author had begun his study with the ichthyological survey of the lentic water bodies in Barak Valley region of Assam (24°10’N – 93°15’E) with the identification of the four most widely-affected species of fishes (due to EUS) during July, 1988.

These are:

Macrognathus aral, which portrays lesions on the skin generally in the abdomen and occasionally in the caudal region;

Channa punctatus, which shows lesions on the skin generally at the base of the caudal peduncle and sometimes show reddish swollen eyes (exophthalmos);

Mystus vittatus, which depicts amber-coloured lesions at the base of the rayed dorsal fin and sometimes at the base of the caudal fin;

Puntius conchonius, which exhibits amber-coloured lesions at the base of the dorsal and caudal fins and sometimes in other parts of the body.

Other species affected by the present epidemic, during July, 1988, but not very widely, include the following: *Mastacembelus armatus, Macrognathus pancalus, Salmostoma bacaila, Gudusia chapra, Badis badis, Glossogobius giuris, Ailia coila, Lepidocephalichthys guntea, Clarias batrachus, Cirrhinus mrigala, C. reba, Parambassis ranga,* etc. *Wallago attu* and *Hilsa (Tenualosa) ilisha* have not been found to be widely affected by the prevailing epidemics. Among the Indian major carps, during July, 1988, barring a few *Catla catla* and *Cirrhinus mrigala*, none of the other Indian major carps were found to be affected by EUS. Nevertheless, *Amblypharyngodon mola, Ctenopharyngodon idellus, Rasbora daniconius, Puntius ticto* and *Channa marulius* have been found to be affected only in certain areas of the district at the beginning.

Our continued study revealed that, during the period 1992-1994, the following species had been found to be very severely affected by EUS: *Parambassis ranga, Chanda nama, Nandus nandus,* and *Glossogobius giuris.* Some of the other species affected by EUS, but to a lesser extent during this period, included *Mastacembelus armatus, M. pancalus, Xenentodon cancila,* and *Colisa fasciatus*, etc.

Our subsequent studies indicated that the following species of fishes have been severely-affected by EUS, since 1995, particularly, during the period November-February, causing large-scale mortality among them: *Channa striata, C. punctatus, Anabas testudineus,* and *Clarias batrachus*.

Thus, there has been a differential pattern of spread of EUS among different fish species during different seasons and years (Kar, 2015).

Moreover, our study also revealed a periodicity in the magnitude of the disease among the four most widely affected species (Kar, 2015):

(a) From around mid-July to mid-August, 1988:

Mystus vittatus > *Channa punctatus* > *Macrognathus aral* > *Puntius conchonius*;

(b) From around mid-August to first week of September, 1988:

Mystus vittatus > *Macrognathus aral* > *Puntius conchonius* > *Channa punctatus*;

(c) From around first week of September to around last week of September, 1988:

Mystus vittatus > *Puntius conchonius* > *Channa punctatus* > *Macrognathus aral*;

(d) From around last week of September to around third week of October, 1988:

Puntius conchonius > *Channa punctatus* > *Macrognathus aral* > *Mystus vittatus*.

Our 2002-2004 study revealed that, the highest mortality rate has been found among *Cirrhinus mrigala*, *Channa* spp., *Puntius* spp., *Labeo* spp., and *Clarias batrachus*. Specific Death Rate (SDR) due to EUS calculated on the basis of nmber of deaths during a year/mid-year population (total number of species) x 100, was found to be (22/38) x 100 = 57.89%.

During the said period, the killing power of EUS has been represented by the Case Fatality Ratio (CFR) = Total number of deaths due to EUS/Total nomber.of cases due to EUS x 100. CFR has been calculated species wise and has been found to be high among *Cirrhinus mrigala* (83.72%), followed by *Puntius ticto* (75%), *Channa marulius* (70%), *Mastacembelus armatus* 69.23%), *Anabas testudineus* (53.85%), and, so on (Kar, 2015).

Epidemiology of EUS at the international level

With regard to the Global scenario, more than 100 fish species have been reported to be affected by EUS (Lilley et al., 1992), but, only relatively few reports have been confirmed by demonstrating the presence of the infecting agent.

Some commercially important species are considered to be particularly resistant to EUS. But, not much studies have been done to confirm these observations and investigate the mechanism of resistance. Species reported to be unaffected by EUS outbreaks include the Chinese carps, tilapias, and milkfish (*Chanos chanos)*. Hatai (1994) experimentally injected catfish (*Parasilurus asotus)*, loach (*Misgurnus anguillicaudatus)* and eel (*Anguilla japonica)* with hyphae of *A. invadans* and found them to be refractory to infection. Wada et al. (1996), and Sharifpour (1997) experimentally injected common carp (*Cyprinus carpio)* with zoospores of *Aphanomyces* from MG and EUS outbreaks respectively, and, demonstrated that fungal growth was suppressed by an intense inflammatory response.

Humphrey and Pearce (2006) had reported that, in the Northern Territory of Australia, EUS had been reported in archer fish (*Toxotes chartareus*), barramundi (*Lates calcarifer*), bony bream (*Nematolosa erebi*), chanda perch (*Ambassis agassizii*), fork-tailed catfish (*Arius* sp.), etc.

Notwithstanding the above, in Pakistan, EUS, appeared to be confined to the regions of rivers Chenab and Ravi and their associated irrigation canals in the districts of Kasur, Lahore, Gujranwala, and Sialkot. Wide range of infections and large-scale mortalities had occurred among some of the ichthyospecies, viz., *Channa punctatus*, *Channa marulius*, *Wallago attu*, and *Puntius* sp., etc.

Concomitant to above, in Bangladesh, the most-affected fish species were the *Puntius* spp., *Channa* spp., *Mastacembelus* spp., and, so on. Moreover, there had been reports of variations in the status of susceptibility at the species level among the different genera as revealed during selection of candidate species for aquaculture.

Khan and Lilley (2002) found differences in the occurrence of lesions among different habitats. Moreover, fishes collected by little uncommon fishing gears, like the seine nets, seemed to have a lower prevalence of EUS lesions as compared to fishes collected by more common fishing gears, like the scooping nets, spears, etc. The latter often damaged the body of the fish and could make it more susceptible to disease.

Moreover, the most severely affected species in natural outbreaks are generally bottom dwellers (Llobrera and Gacutan, 1987; Chondar and Rao, 1996) or the fishes which possess air-breathing organs. Among the snakeheads, no particular size group appears to be more susceptible, with affected fish usually ranging from 40 to 900 g (Cruz-Lacierda and Shariff, 1995). Moreover, the IMC juveniles were more affected than the adults (AAHRI, ACIAR, IoA, and NACA, 1997).

Further, several EUS-affected snakehead and clariid catfish species occur in Africa and in Central Asia, suggesting that, there is potential for further spread of the disease to these areas, and, the EUS did spread.

In 2006, fish caught in the Chobe-Zambezi River were found to be EUS-affected as confirmed by the OIE-FAO- supported reference Laboratory in Thailand. In 2007, the disease was reported in Namibia and Zambia. EUS was reported in the Kafue River and in its tributaries (Chongwe River) in 2010 and 2011 respectively.

The fishes of lake Kariba and lake Cahora Bassa (large impoundments in lower part of Zambezi River supporting significant fisheries) were EUS-affected. Lake Kariba has one of the largest aquaculture facilities in sub-Saharan Africa. In 2010, EUS was reported from the Okavango Delta in Botswana and in 2011 from the Western Cape Province of South Africa. Biodiversity of the fishery, as a result, had been threatened, thus, posing food insecurity to > 700,000 people in the region.

The Geographic Information System (GIS) had helped to map the distribution of the disease. Results of the study had implicated a number of predisposing environmental factors.

The latest outbreak of EUS had been reported from Canada. A new susceptible species of brown bullhead, *Ameiurus nebulosus* seemed to had been affected by EUS.

It appeared that the disease has potential to spread further, because of its epizootic nature and broad susceptible host range.

To prepare a working hypothesis

Based on the analysis of time, place and fish data, working hypotheses are usually developed for further investigation. These may concern one or more of the following:

(a) Whether the outbreak is common source or propagating;

(b) If a common source, whether it is point or multiple exposure;

(c) The mode of transmission: contact, vehicle or vector. Any hypothesis should be compatible with all the facts;

(d) Corrective action could be taken based on the more realistic hypotheses.

Intensive follow up

This generally includes clinical, pathological, and microbiological examinations, together with examinations of water quality data and recent meteorological data. Epidemiological follow-up will include detailed analyses of these data as well as the search for additional cases on other premises. Flow charts of management and movements of fish, water, and equipment, for example, may be required as part of this process. Transmission trials may be necessary where additional infectious agents, such as bacteria or ectoparasites, are suspected as component causes of the outbreak.

Details of the outbreak of EUS, including the Inter- and Intra-continental status had already been elucidated earlier.

Management of epidemiologic episodes

Epidemiological evidence suggests that, EUS outbreaks in farmed fish are more severe when stocking densities are high. Stocking densities should be maintained as low as possible and farmed populations subjected to minimal stress. In particular, fish could be monitored to ensure that bacterial and parasitic skin pathogens do not cause problems. Further, the abiotic factors, like DO are to be at the optimum level. EUS-resistant fishes are preferably to be cultured during the EUS-outbreak period.

Concomitant to above, from an epidemiological perspective, and to accommodate the apparently multifactorial nature of EUS, Lilley et al., (1998) used the concepts of "necessary cause", "component cause" and "sufficient cause". Each combination of various "component causes" which result in disease is known collectively as a "sufficient cause" for that disease. However, under different circumstances, different combinations of "component causes" may constitute "sufficient cause" for a disease and these "sufficient causes" for a particular disease have in common at least one "component cause", known as "necessary cause" which must always be present for that disease to occur.

Background involvement in EUS

Bacterial culture revealed occurrence of haemolytic *E. coli*, *Aeromonas hydrophila, Pseudomonas aeruginosa, Klebsiella* sp., *Staphylococcus epidermidis* in the surface lesions as well as in the gut, liver, gills, heart, kidney. and gonads of sick fishes, all of which have been found to be sensitive to Chloramphenicol, Septran, Gentamycin, etc.

Mycotic involvement in EUS

Fungal isolation revealed the occurrence of *Aphanomyces* sp. with concomitant occurrence of the same fungal genus in histological sections of EUS-affected fishes.

Viral involvement in EUS

Inoculation of 10% tissue homogenate of EUS-affected *Clarias batrachus* into 80% confluent monolayer form BF2 and RTG fish cell lines in Leiboitz L-15 medium, revealed progressive CPE which was passable in subsequent cultures, thus, indicating the "isolation" of virus. The filterable biological particles were different from those described by Frerichs et al. (1986).

Further, recent studies revealed the detection of Ranavirus infection in cultivated carps of North-East India (Kar, 2007, 2013, 2015, 2019; Riji et al., 2016).

Electron microscopic studies

Electron microscopic studies with the ultra-thin sections of still-occurring EUS-affected fish tissues, revealed the presence of virus-like particles (inclusion bodies), and, preliminarily, the picobirna virus has been electron microscopically identified as the primary aetiological agent of EUS (Kar, 2015).

Summary of EUS investigation

EUS has been causing large-scale mortality among the freshwater fishes since 1988, initially affecting four species of fishes very widely. Our study revealed fluctuation in the intensity of the disease in relation to species affected. Large haemorrhagic cutaneous ulcers, epidermal degeneration and necrosis followed by sloughing of scales are the principal symptoms of EUS. Low total alkalinity (TA) of water could be a pre-disposing "stress factor". Sick fishes show low haemoglobin and polymorphs, but high ESR and lymphocytes. Communicative nature of EUS revealed variation in time gap between fish and infection in different species. Inoculation of microbes in the test animals did not reveal of any sign of ulcerations for two years. Bacterial culture revealed occurrence of haemolytic *E. coli, Aeromonas hydrophila, Pseudomonas aeruginosa, Klebsiella* sp., and *Staphylococcus epidermidis* in the surface lesions as well as in the gut, liver, gills, heart, kidney, and gonads of sick fishes, all of which have been found to be sensitive to Chloramphenicol, Septran, Gentamycin, etc. Fungal isolation revealed the occurrence of *Aphanomyces* sp. with concomitant occurrence of the same fungal genus in histological sections of EUS-affected fishes. Histopathological (HP) studies showed focal areas of increased fibrosis and chronic inflammatory cell infiltration in muscles, focal areas of fatty degeneration of hepatocytes surrounding the portal triads in the liver.

CONCLUSIONS

EUS is a global pandemic. EUS attack is specific to fish only.

Radioactivity had no role in EUS infection.

Organic pollution of water and soil were not the reasons for EUS pandemic.

EUS pandemic was not due to any heavy metallic contamination.

EUS has associated bacteria, fungi and viruses. Bacterial flora causing co-infection included *E.coli*, *Pseudomonas aeruginosa*, *Klebsiella* sp., *Aeromonas hydrophila, Staphylococcus epidermitis,* etc.

Aphanomyces invadans was the principal mycotic flora associated with EUS infection.

A primary viral aetiology was established in tissue culture.

Electron microscopic study revealed it to be a birna virus.

Effective measures must be adopted to prevent fish mortality.

EUS vaccine yet to be developed. Vaccine preparation for EUS to be intiated effectively.

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REPRODUCTIVE BIOLOGY OF THE TIGRIS SCRAPER, *CAPOETA UMBLA* (HECKEL, 1843) POPULATION LIVING IN SOLHAN CREEK OF MURAT RIVER (BİNGÖL, TURKEY)

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KEYWORDS: *Capoeta umbla*, reproductive cycle, maturity, fecundity, Solhan Creek.

ABSTRACT

We studied the reproductive traits in 23 of 190 individuals of *Capoeta umbla* caught monthly in the Solhan Creek of the Murat River between April 2017 and March 2018. The sex ratio (F:M) was found to be 1:1.11. The macroscopic examination of the gonads and gonado-somatic index indicated that the reproductive period lasted from May to August with peak activity in May. The fecundity ranged from 2,000 to 9,000 oocytes, and it correlated with the total length and body weight. This work represents the first attempt to investigate the reproductive traits of the *Capoeta umbla* population in the Solhan Creek. The results provide information on the reproductive biology and contribute to the conservation of the fish population and its sustainable management.

RÉSUMÉ: Biologie reproductive du grattoir du *Capoeta umbla* (Heckel, 1843) population vivant à Solhan bras de mer de la rivière Murat (Bingöl, Turquie).

Sur 190 individus de *Capoeta umbla* capturés chaque mois dans le ruisseau Solhan et la rivière Murat entre avril 2017 et mars 2018, les aspects reproductifs de 23 individus ont été étudiés. Le sex-ratio (F:M) était de 1:1,11. L'examen macroscopique des gonades et de l'indice gonado-somatique ont indiqué que la période de reproduction dure de mai à août avec un pic d'activité en mai. Les estimations de la fécondité variaient de 2.000 à 9.000 ovocytes, et elles ont été considérées comme corrélées avec la longueur totale et le poids corporel. Ce travail représente la première tentative d'étudier les aspects reproductifs de la population de *Capoeta umbla* à Solhan Creek. Les résultats fournissent des informations fondamentales sur la biologie de la reproduction et contribuent à la conservation de la population de poissons et à sa gestion durable.

REZUMAT: Biologia reproductivă a populației de *Capoeta umbla* (Heckel, 1843) care trăiește în Pârâul Solhan al Râului Murat (Bingöl, Turcia).

Din 190 de indivizi de *Capoeta umbla* capturați lunar în pârâul Solhan al râului Murat, între aprilie 2017 și martie 2018, au fost studiate aspectele reproductive la 23 dintre ei. Raportul pe sexe (F:M) a fost găsit ca fiind 1:1,11. Examinarea macroscopică a gonadelor și a indicelui gonado-somatic a indicat faptul că perioada de reproducere durează din mai până în august, cu activitate maximă în luna mai. În ceea ce privește fecunditatea, numărul ovocitelor a variat între 2.000 și 9.000, și s-a văzut că este corelat cu lungimea totală și greutatea corporală. Această lucrare reprezintă prima încercare de a investiga aspectele reproductive ale populației de *Capoeta umbla* din Pârâul Solhan. Rezultatele oferă informații fundamentale despre biologia reproducerii și contribuie la conservarea populației de pești și la gestionarea durabilă a acesteia.

INTRODUCTION

Fish around the world are significantly impacted by direct or indirect human impact, and they have a decreasing ecological trend due to this impact (Sheridan, 2008; Trichkova et al., 2009; Jeeva et al., 2011; Khoshnood, 2014; Sosai, 2015; Gebrekiros, 2016; Kar and Khynriam, 2020; Radkhah and Eagderi, 2020; Reynaldo de la Cruz, 2020; Rios, 2021; Su et al., 2021).

Studies on the reproductive biology of fish are important to plan better conservation and management strategies of fishery resources (Grandcourt, 2009; Muchlisin et al., 2010). Reproductive biological traits play a basic role in fishery management (Miller, 1984; Komalefe and Arawomo, 2007). Knowledge of the length of the fish at first maturity and spawning season is essential for local authorities to set the suitable fish length and time for fishing (Dinh, 2018). Fecundity is among the most important aspects of fish biology, which must be understood to explain the variation in the population level as well as to make efforts to increase the fish harvest (Das et al., 1989). Determining the fecundity and the development of sexual maturity in fish is fundamental to fishery science (Brown et al., 2003). In fish biology, the analysis of life history traits related to reproduction has mainly focused on females, in part because the offspring production is limited to a greater degree by the egg production, rather than by the sperm production (Helfmann et al., 1997; Murua and Saborido-Rey, 2003).

The genus *Capoeta*, Cyprinidae, is distributed in southern China, northern India, Turkmenistan, Lake Aral, the Middle East, and Anatolia (Bănărescu, 1999). Its representatives inhabit mainly fast flowing streams and rivers and are also found in lakes and springs (Turan et al., 2006). Freyhof (2014) and Esmaeili et al. (2016) reported the presence of *Capoeta umbla* in Iran (Tigris River basin), Iraq, Syria, and Turkey (Asian part) and listed it in the Least Concern (LC) category. *Capoeta umbla* is called black fish, Zeruke, sarı balık, or Siraz (Turkish) (Türkmen et al., 2002; Çiçek et al., 2016). Some investigations regarding various biological traits of *Capoeta umbla* have been carried out in Tercan Dam Lake and Tuzla River (Gül et al., 1996), Hazar Lake (Yüce and Şen, 2003), and the Ceyhan Dam Lake (Kara et al., 2010).

Capoeta umbla is the most commercially valued fish for the local people around the Murat River. Since the current work has been carried out on *Capoeta umbla* in the Murat River and its creeks, some general data regarding the reproduction of this species in the Solhan Creek are presented here. Accordingly, this study aims to enrich the knowledge on the reproductive traits of *Capoeta umbla*, such as the sex ratio, reproductive season, fecundity, and its relationship with total length and total weight, which may be used for fishery management.

MATERIAL AND METHODS

The Solhan Creek is one of the important branches feeding the Murat River and is located in upper Fırat of Eastern Anatolia (Kılıç, 2015). This creek is 39 kilometers from Bingöl City.

For each fish, the total length (TL) was approximated to the nearest mm and the total weight (TW) to 0.1 g. The sex (male, female) and gonads were analysed macroscopically and the gonad weight (GW) was approximated to 0.01 g. The maturity stages of the gonads were determined with reference to the universal scale, considering five stages in accordance with Holden and Raitt (1974) (Tab. 1). Fish with gonads at stage greater than or equal to three were considered mature (Fontana, 1979).

Table 1: A five-point maturity scale for partial spawners.

Stage	State	Description
I	Immature	Ovary about 1/3 length of body cavity. Ovaries pinkish, translucent. Eggs not visible to naked eye.
II	Maturing	Ovary about 1/2 length of body cavity. Ovary pinkish, translucent. Eggs not visible to naked eye.
III	Ripening	Ovary and testis are about 2/3 length of body cavity. Ovary pinkish-yellow colour with granular appearance. No transparent or translucent eggs visible.
IV	Ripe	Ovary from 2/3 to full length of body cavity. Ovary orange-pink in colour with conspicuous superficial blood vessels. Large transparent, ripe eggs visible.
V	Spent	Ovary shrunken to about 1/2 length of body cavity. Walls loose. Ovary may contain remnants of disintegrating opaque and ripe eggs, darkened or translucent.

The sex ratio is defined as the proportion of each sex, determined by macroscopic observation of gonads in a given population (Avşar, 2016). The principal hypothesis supposes that there is equal sex ratio. This was evaluated with a chi-square test (χ^2) (Sümbüloğlu and Sümbüloğlu, 2019).

To quantify the changes in the gonad weight during the annual sexual cycle and to determine the spawning season, we calculated the gonad-somatic index (GSI) for 190 specimens (90 females and 100 males) by the following formula: GSI = (GW/SW) x 100, GW: gonad weight (g), SW: somatic weight (g) (body weight minus gonad weight) (Avşar, 2016).

The gravimetric or weight method has been successfully used by Doha and Hye (1970), Bagenal and Braum (1978), Shafi et al. (1978), Dewan and Doha (1979), Sarker et al. (2002). It offers the best possibility of minimizing errors owing to its simple and easy sampling techniques. This method has been used for its greater efficacy compared to the other methods (Bitty Blanchard et al., 2003). The gravimetric method was applied as follows: before estimating the fecundity, a sample of 0.1 g was taken separately from the anterior, posterior, and middle region of the lobe of each ovary and weighted.

The fecundity (F1) was estimated by using the following equation (Yeldan and Avşar, 2000):

$$\text{Fecundity (F1)} = \frac{\text{No. of eggs in sub sample} \times \text{Gonad weight}}{\text{Weight of sub sample}}$$

Then, by taking the mean number of three sub-sample fecundities (F1, F2, and F3), the individual fecundity for each female fish was calculated by the following equation:

$$\text{Fecundity (Fe)} = \frac{F1 + F2 + F3}{3}$$

The total length and body weight of fish were estimated to establish a mathematical relationship with fecundity: $F = a.L^b$, where F = fecundity (dependent variable), L = total fish length (cm); and the regression equation: F = a + b (W-GW), where F = Fecundity, GW = gonad weight (g), W = total fish weight (g), a = regression constant, and b = regression coefficient (Bagenal and Braum, 1987; Avşar, 2016).

RESULTS AND DISCUSSION

A total of 190 specimens were examined in our study. The macroscopic study of gonads showed that the sample consisted of 90 females and 100 males (Figs. 1a-b).

Figure 1a: Female gonads.

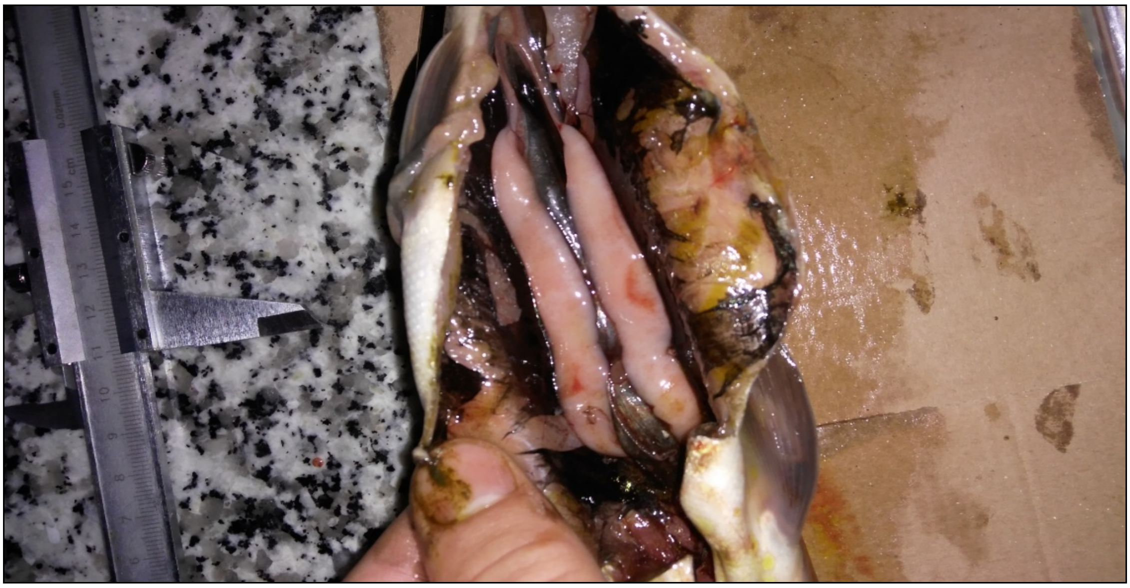

Figure 1b: Male gonads.

The gonado-somatic index indicated that the reproductive period lasted from May to August with peak activity in May. The highest average values of GSI were found in May, 11.57 and 11.74 for male and female respectively, while the lowest average values were in July (1.93), respectively (Fig. 2).

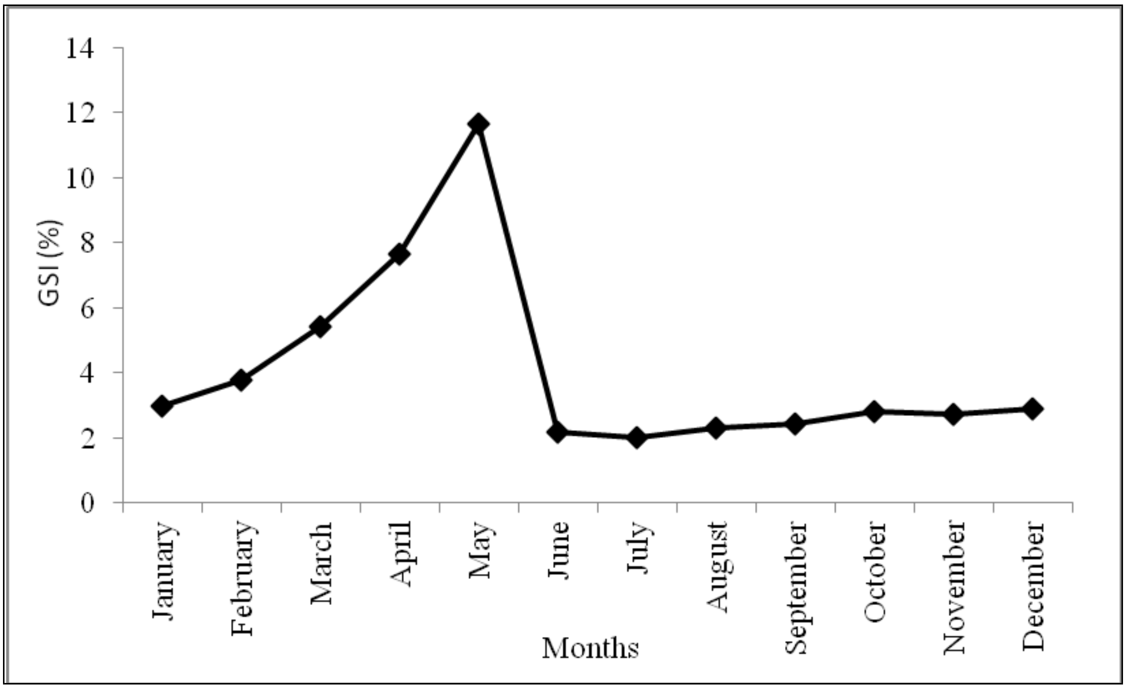

Figure 2: Gonadosomatic index of *Capoeta umbla*
in the Solhan Creek in the Murat River according to months.

The fecundity of 169 mature female fish was estimated within the range from 2,000 to 9,000 oocytes for the corresponding total length and body weight of the fish: from 19.5 cm and 76.00 g to 32.2 cm and 333 g, respectively.

The exponential relationship between the fecundity and total length was expressed as $F = 1.421 \times TL^{2.527}$ ($R^2 = 0.463$) (Figs. 3a-b).

The diagram obtained from the fecundity and body weight showed a positive linear relationship that was expressed as $F = 2107TW + 1858$ ($R^2 = 0.390$).

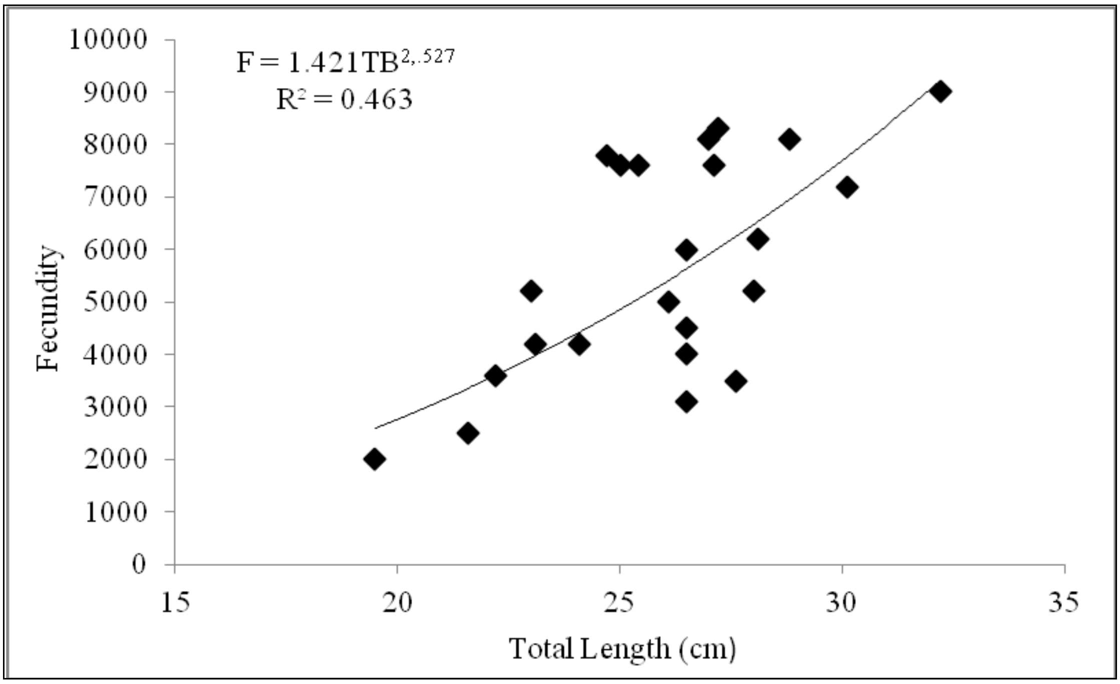

Figure 3a: Relationship between fecundity and total length of *Capoeta umbla* in the Solhan Creek of the Murat River.

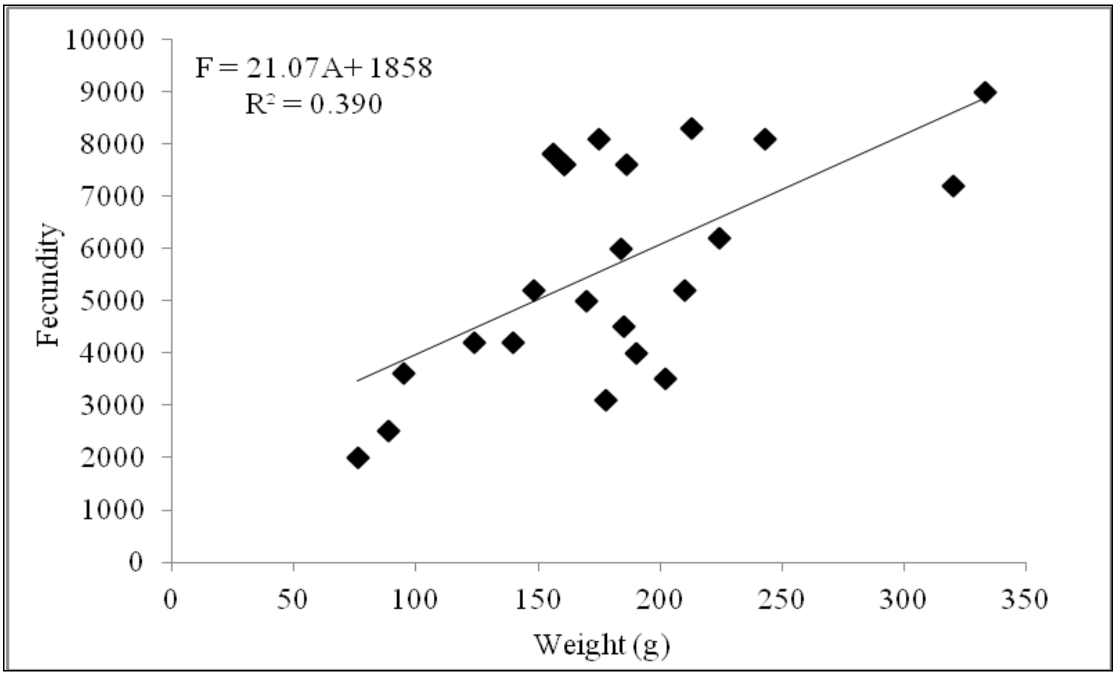

Figure 3b. Relationship between fecundity and weight of *Capoeta umbla* in the Solhan Creek of the Murat River.

It was found that the absolute fecundity was slightly correlated with the total body length and the results revealed that the fecundity increased as the female fish grew in dimension.

A total of 190 specimens of *Capoeta umbla* were collected during the studied period, comprised of 52.63% males and 47.37% females. The sex ratio (F:M) was 1:1.11 and significantly different from 1:1 (t-test, P > 0.05). This agrees with some researchers who studied other *Capoeta umbla* populations and pointed out that the annual sex ratio has dominance of males (Tab. 2). Nikolsky (1980) indicated different sexual dispersions of the same species in various populations. It is well known that the sex ratio in most species is close to one, but it may vary from species to species, from one population to another in the same species, and from year to year in the same population.

Table 2: Sex ratio of *Capoeta umbla* populations in the relevant literature.

Researcher	Locality	Female%	Male%	Sex Ratio
Yüksel (2002)	Hazar Lake	52.48	47.52	D:E = 1.10:1
Yılmaz et al. (2003)	Fırat River	48.51	51.49	D:E = 0.94:1
Güneş (2007)	Tuzla Stream	47.56	52.44	D:E = 0.91:1
	Tercan Dam Lake	51.08	48.92	D:E = 1.04:1
Çoban and Şen (2011)	Hazar Lake	46.97	53.03	D:E = 0.72:1
	Keban Dam Lake	42.11	57.89	D:E = 0.88:1
Çoban et al. (2013)	Hazar Lake	65.09	34.91	D:E = 1.87:1
Gündüz et al. (2015)	Uzunçayır Dam Lake	35.42	64.58	D:E = 0.55:1
Çiçek et al. (2016)	Dicle Nehri	67	15	D:E = 4.47:1
Eroğlu et al. (2018)	Özlüce Dam Lake	59.31	40.69	D:E = 1.46:1
This study	Murat River	47.64	52.36	D:E = 1:1.11

The analysis of the GSI index and data of the maturity stages suggests that the main spawning season is summer, beginning in May and lasting till July (Fig. 1). The spawning seasons of *Capoeta umbla* were compared to the relevant studies (Tab. 3).

Table 3: Spawning seasons (J – D, January to December) of *Capoeta umbla* according to previous studies.

Researcher	Locality	J	F	M	A	M	J	J	A	S	O	N	D
Özdemir (1982)	Hazar Lake				X	X	X						
Şen (1988)	Kaleci Lake			X	X	X	X						
Öztürk (1996)	Hazar Lake						X	X					
Türkmen et al. (2002)	Karasu River					X	X						
Yüksel (2002)	Hazar Lake				X	X	X						
Bayır et al. (2007)	Hınıs Stream					X	X						
Yüce and Şen (2003)	Hazar Lake					X	X						
Güneş (2007)	Tuzla Stream-Tercan Lake			X	X	X	X						
Çoban et al. (2013)	Hazar Lake				X	X	X						
This study	Solhan Creek, Murat River					X	X	X					

The spawning season exhibited a different pattern in other areas (Tab. 3). It may be said that the starting and finishing time of reproduction might include different months because of the ecological and climatic conditions. The spawning cycle is closely related to temperature. The spawning periods of fish vary also with respect to such ecological differences as stagnant or running water, as well as altitude, temperature, and quality of food. (Nikolsky, 1980)

Data on fish fecundity are much less available than data on maturity and sex ratio (Tomkiewicz et al., 2003). Therefore, the authors use different methods to predict fecundity. The fecundity varied from 2,000 to 9,000 oocytes for fish ranging in total length and body weight from 19.5 cm and 76.00 g to 32.2 cm and 333 g in the Solhan Creek. Ünlü (1991) and Türkmen et al. (2002) reported a fecundity of 3,754 to 35,859 oocytes and 4,713 to 18,240 oocytes for females, respectively, while Ekmekçi (1996) specified it from 10,840 to 12,175 oocytes in Sariyer Dam Lake. Yıldırım and Aras (2000) reported a fecundity between 1,768 to 29,121 oocytes from the Çoruh River. Erdoğan (1998) reported similar values of fecundity 1,711 to 16,254 oocytes from the Aras River, while Türkmen et al. (2002) estimated it between 3,754 to 35,859 oocytes for females from the Karasu River. Fecundity correlates with the fish length and weight accordig to Bircan and Polat (1995), Erdoğan (1998), Yıldırım and Aras (2000), and Çoban et al. (2013). A basic property of fecundity is its increase during the growth of the fish. A large fish produces more eggs than a small one. The correlation between fecundity and body weight in most fishes is higher than that between fecundity and total length (Nikolsky, 1980). Çoban et al. (2013) reported fecundity values between 1,860 and 15,624 eggs in fish ranging from 11.8 to 19.5 cm in length caught in the Hazar Lake. The fecundity of *Capoeta umbla* was strongly correlated to TL and TW, due to the high value of the determination parameter (*r2*) obtained from the relationships. Our study showed that the fecundity increased as the female fish grew. Larger fish with a greater visceral space for egg development have larger ovaries, and thus more eggs than smaller fish. Although variation occurs between years in response to environmental conditions (Bagenal and Braum, 1978; Mitton and Lewis, 1989), it is also generally accepted that egg size also increases with body length (Wright and Shoesmith, 1988; Zivkov and Petrova, 1993; Moyle and Cech, 2004). However, variation in fecundity between populations of the same species and between years within a population is well known (Bowering, 1978; Pinhorn, 1984; Gundersen, 1990; Kraus et al., 2002; Bitty Blanchard et al., 2003; Power et al., 2005; Rideout and Morgan, 2007). Fecundity is influenced by age, size, fish species, feeding of fish, season, and environmental conditions (Nikolsky, 1980). Differences between this study and other studies can be explained by the above-mentioned reasons.

CONCLUSIONS

The tigris scraper *Capoeta umbla* is an important fishery resource in the Murat River, Eastern Anatolia of Turkey, due to their high commercial value. Thus, the aim of this work was to study the reproduction to understand the population dynamics of this species for ensuring sustainable and rational exploitation of their stocks in the studied region. To achieve sustainable maximum production in the population of this species in the Murat River basin, the fishery activities should be forbidden between May and July.

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OCCURRENCE, ABUNDANCE AND DISTRIBUTION OF BLEAK, COMMON SPIRLIN, AND SUNBLEAK IN THE ENVIRONMENTAL GRADIENTS OF SMALL RIVERS (TATARSTAN)

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KEYWORDS: bleak, common spirlin, sunbleak, environmental factors, species.

ABSTRACT

The probability of occurrence, distribution, and abundance of bleak, common spirlin, and sunbleak in 316 small rivers of the Republic of Tatarstan were studied. The studied region has a high geographical and environmental heterogeneity. The impact of environmental factors on species occurrence was analyzed with generalized linear models. Among the selected fish, sunbleak had the highest probability of occurrence, and bleak had the highest abundance. Elevation was the only environmental variable significantly affecting the probability of occurrence of all three species. With an increase in elevation, the probability of occurrence of bleak, common spirlin, and sunbleak significantly decreased. Optimum values and niche breadth differed significantly between fish species for some of the environmental variables.

ZUSAMMENFASSUNG: Vorkommen, Abundanz und Verteilung von Ukelei, Gemeinem Spirlin und Moderlieschen in den Umweltgradienten kleiner Gewässer (Tatarstan).

Die Wahrscheinlichkeit des Vorkommens sowie der Verteilung und Abundanz von Ukelei, Spirlin und Moderlieschen wurden in 316 kleinen Flüssen der Republik Tatarstan untersucht. Die Untersuchungsregion hat eine hohe geographische Heterogenität, wie auch die Umwelt. Der Einfluss der Umweltfaktoren auf das Vorkommen der Arten wurde mithilfe generalisierter linearen Modelle analysiert. Unter den ausgewählten Fischen hat Moderlieschen die höchste Auftrittswahrscheinlichkeit, während Ukelei die höchste Abundanz hat. Die Höhenlage der Standorte war die einzige Umweltvariable, die das Vorkommen aller drei Fischarten wesentlich beeinflusste. Bei steigender Höhenlage nimmt die Wahrscheinlichkeit ihres Vorkommens von Ukelei, Spirlin und Moderlieschen deutlich ab. Die optimalen Werte sowie die Nischenbreite unterscheiden sich bei einigen Umweltvariablen wesentlich zwischen den untersuchten Fischarten.

REZUMAT: Ocurența, abundența și distribuția obletului, bldiței și plevuștii în gradienții de mediu ai râurilor mici (Tatarstan).

Au fost studiate probabilitatea apariției, distribuției și abundenței obletului, bldiței și plevuștii în 316 râuri mici din Republica Tatarstan. Regiunea studiată are o heterogenitate geografică și de mediu ridicată. Impactul factorilor de mediu asupra apariției speciilor a fost analizat cu modele liniare generalizate. Dintre peștii selectați, plevușca a avut cea mai mare probabilitate de apariție, iar obletul a avut cea mai mare abundență. Altitudinea a fost singura variabilă de mediu care a afectat în mod semnificativ probabilitatea de apariție a tuturor celor trei specii. Odată cu creșterea altitudinii, probabilitatea de apariție a obletului, bldiței și plevuștii a scăzut semnificativ. Valorile optime și lățimea nișei au diferit semnificativ între speciile de pești pentru unele dintre variabilele de mediu.

INTRODUCTION

Information on the occurrence, distribution, abundance and ecological preferences of various taxa of living organisms in the era of global climate change (Buisson et al., 2013; Comte et al., 2013; IPCC, 2014; Askeyev et al., 2020) is necessary for monitoring the state of various ecosystems, rational use of biological resources, and for the preservation of rare and endangered species. It is important to know which environmental factors limit the distribution, occurrence, and number of species, as well as what is their optimum ecological niche in terms of environmental factors. Knowledge of these ecological variables of the biocenosis is important for understanding the functional role of biota in ecosystems and can be used in bioindication of the state of aquatic ecosystems. In modern times, rivers are among the ecosystems most disturbed by humans (Brookes et al., 1983; Gregory, 2006). Rivers are often used as reservoirs, sources of energy supply, places of passage for navigable transport, places for tourism and recreation, and for wastewater discharge (Brookes et al., 1983; Gregory, 2006). All these factors, acting together with climate change, can lead to extremely negative consequences, including the decreasing or the disappearance of entire populations of various species from bodies of water (Buisson et al., 2013; Bănăduc et al., 2021).

The Republic of Tatarstan has a relatively high taxonomic diversity of fish species (Kuznetsov, 2005; Askeyev et al., 2015, 2017), which have different preferences for environmental factors. In the current study, we selected the following fish species (Fig. 1): bleak – *Alburnus alburnus* (Linnaeus, 1758), common spirlin – *Alburnoides bipunctatus* (Bloch, 1782) (the species is listed in the Red Book of the Republic of Tatarstan, 2016), and sunbleak – *Leucaspius delineatus* (Heckel, 1843). These species have a common Ponto-Caspian origin (Nikolsky, 1974; Kuznetsov 2005), have a relatively close genetic relationship, are close in morphological size and live together in bodies of water within the studied region. In this regard, it would be interesting to know if there are differences between these fish species in preferences for environmental factors in small rivers of the Republic of Tatarstan.

The main objectives of the study were: (1) to estimate the current occurrence and abundance of fish, (2) to identify environmental factors affecting the probability of occurrence of bleak, common spirlin, and sunbleak, and (3) to calculate the optimum points and widths of the ecological niches for the main environmental factors.

MATERIAL AND METHODS

Study area

The Republic of Tatarstan is southeast of the Russian Plain. It is within the northern part of the Middle Volga region, at the confluence of the Volga and Kama rivers, and includes two natural zones – forest and forest-steppe (Minnikhanov, 2005).

The total area of the Republic of Tatarstan is 67,800 km^2. In latitude, the republic occupies a middle position in the European part of Russia between 53°58’N and 56°40’N, in longitude it is between 47°15’E and 54°15’E (Minnikhanov, 2005). This location determines the significant severity and continentality of the climate. Average annual temperatures range from 2.0-7.0°C, with average monthly temperatures from –14°C to –12.1°C in January and 19°C to 21°C in July (Minnikhanov, 2005).

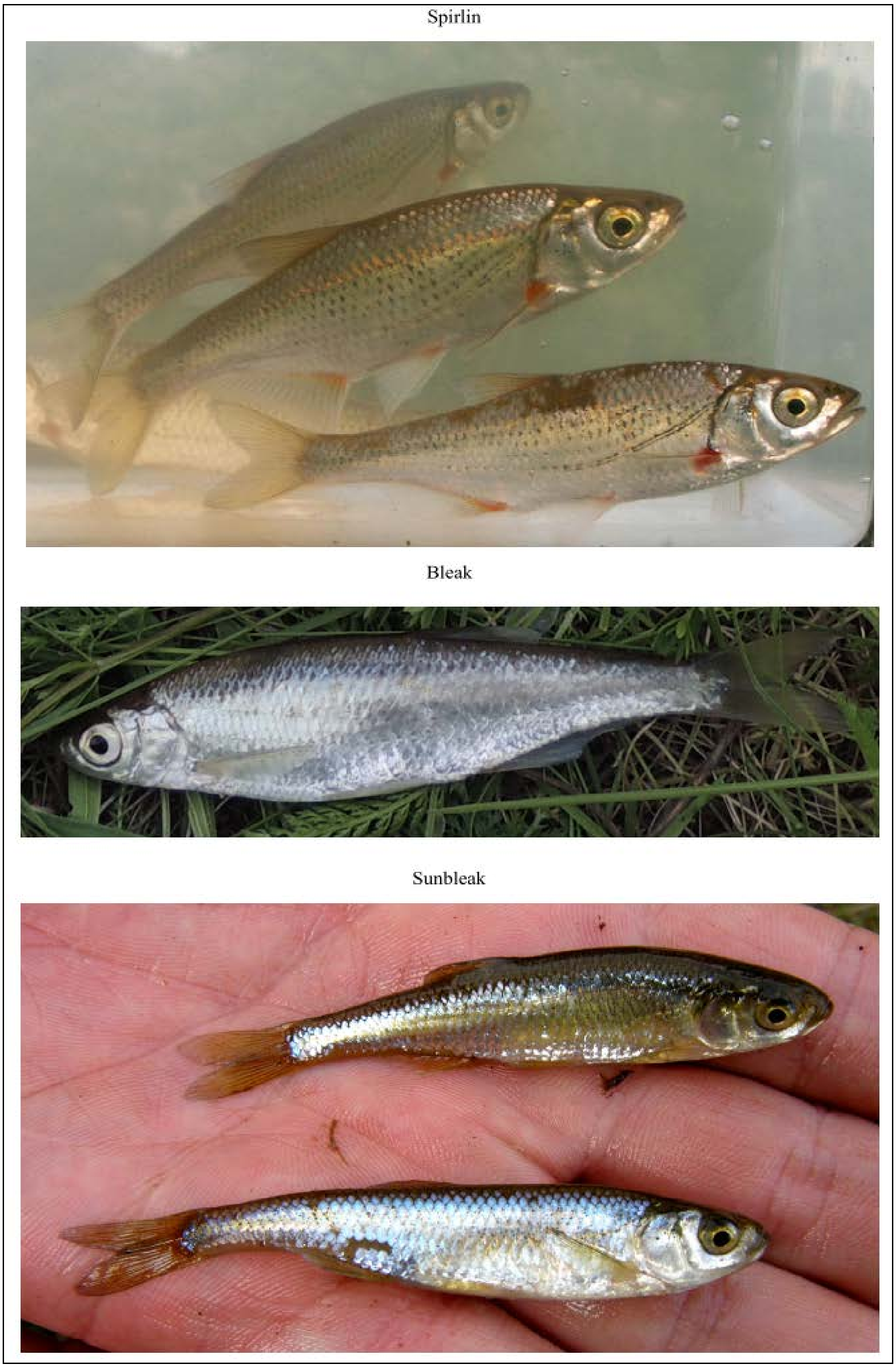

Figure 1: Photos of the investigated species of fish.

We focused on the fish assemblages of small rivers (length up to 500 km). We excluded rivers impacted by large reservoirs. Fish sampling was conducted at 316 locations (Fig. 2). The following seven environmental variables were obtained for each site: elevation (altitude) above sea level (from 53.2 to 270 m, mean 105.5 m, SD-standard deviation 39.1 m), mean width (from 0.5 to 55 m, mean 7.7 m, SD 10.3 m), mean depth (from 0.15 to 1.7 m, mean 0.71 m, SD 0.31 m), water velocity (from zero to one m/s, mean 0.31 m/s, SD 0.16 m/s), trees/bush cover along banks (from zero to 100%, mean 47.9%, SD 27.5%), dominant bottom substrate (1 – mud, 2 – clay or peat, 3 – sand, 4 – gravel, 5 – small pebbles, 6 – large stones up to 150 mm, 7 – large stones 150-300 mm, 8 – boulders > 300 mm) and human impacts (as a 7 point scale, 0 – no agriculture or forestry, 1 – light agricultural impact – hayfields, weak grazing and forestry at a distance of 0-250 m from the river bank, 2 – moderate agricultural impact – average grazing at a distance of 0-250 m from the river bank, the presence of a ford and a watering hole for livestock, 3 – strong agricultural impact – strong grazing with cattle driving trails visible, arable land, and sheds for animals at a distance of 0-250 m from the river bank, 4 – moderate agriculture impact and oil pollution – average grazing, and mining of oil and gas at a distance of 0-250 m from the river bank, 5 – urban impact – river site in town or big village, 6 – strong oil and chemical pollution – chemical or oil odor is felt and seen).

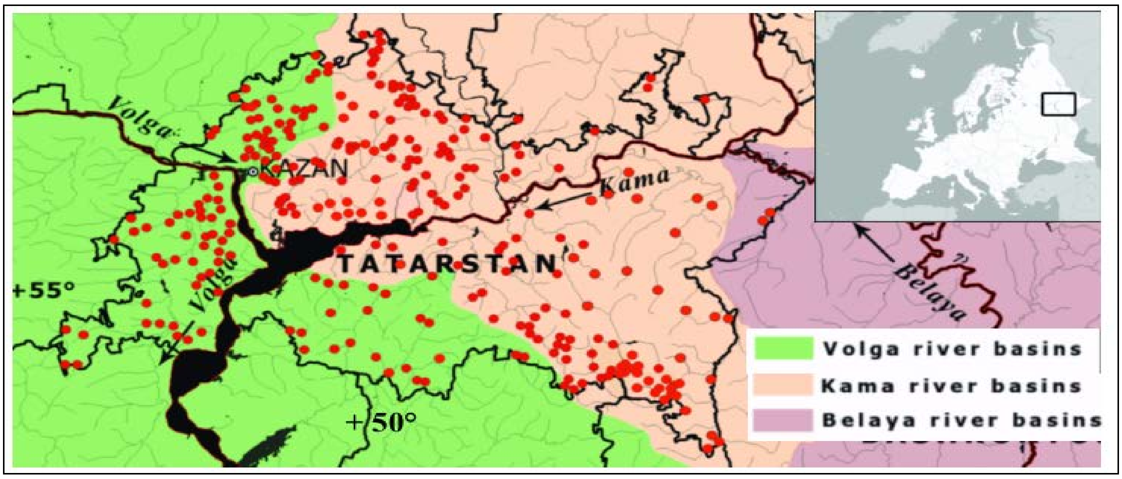

Figure 2: Distribution of the sampling sites in the Tatarstan (location within Europe).

Fish assemblage data

Fieldwork was carried out from May to October 2010-2020 during reduced summer flows. Fish samples were collected during active wading catches of similar duration (60 min.). In smaller rivers, four people fished by seining and dip netting across the full width of the river. Two people, one at each end, pulled the seine through the water until they reached the shore, beaching the seine on dry ground. We used three lengths of nets, depending on the width of the river: 5 – 15 m in length, 1.2 – 1.5 m high, 5 x 5 mm mesh in the wings, 3 x 3 mm in bags. Dip nets were of diameter 50-70 cm, with 4 x 4 mm mesh. Lengths of between 200 m (smaller rivers) and 400 m (larger rivers) of the river sites were sampled. For determining the length of the site, we followed the recommendations for catching fish by FAME Consortium (2004). Caught fish were placed in a plastic basin, identified, counted, and measured at the end of each catch session. After each session ≥ 90% of fish were returned to the water. Identification of fish was carried out according to Maitland and Linsell (2009) and Makeeva et al. (2011). For each site, we calculated the occurrence and abundance of each fish species.

Data analysis

Relationship between fish species and environmental variables

For each of the three fish species the nature and strength of relationships with the seven environmental parameters was examined using binary logistic regression with the environmental variables as predictors. Only statistically significant variables were retained in these regressions. To assess the accuracy of the final models, we used the area under the ROC curve (AUC), which indicates the predictive performance expressed as an index ranging from 0.5 to 1. The accuracy of the model was interpreted after Swets (1988) as follows: 0.90-1.00 excellent; 0.80-0.90 good; 0.70-0.80 fair; 0.60-0.70 poor; 0.50-0.60 fail.

Species optimums and niche breadth

Species optimums in terms of fish numbers for each environmental variable were calculated in order to rank species by habitat preferences. This model fits Gaussian response models to species abundances along an environmental gradient. The fitted parameters are optimum (i.e. average) and niche breadth/tolerance (i.e. standard deviation). The algorithm is based on weighted averaging (ter Braak and van Dam, 1989).

Calculation and visualization were done in PAST version 4.04 and XLSTAT 2021.

RESULTS AND DISCUSSION

Probability of occurrence of bleak, common spirlin and sunbleak in the rivers of the Republic of Tatarstan and other regions of Europe

Sunbleak had the highest probability of occurrence (31%), followed by bleak (26%), and common spirlin (9%); they inhabit all large river basins in the study area. During the study period, 3,483 bleak individuals were caught (mean 11; SD 39.7); 1,777 individuals of sunbleak (mean 5.6; SD 42.4), and 809 individuals of common spirlin (mean 2.6; SD 14.7).

The probability of occurrence of sunbleak in the Republic of Tatarstan is much higher than elsewhere in Europe. In France, the frequency of occurrence of this species is 18.6% (Maire et al., 2016), in Hungary 5.5% (Saly et al., 2011), in northeastern Germany – 3% (Fieseler and Wolter, 2006), and in Lithuania 3% (Stakenas, 2002).

The probability of occurrence of bleak in European rivers varies greatly, but in general it is lower than in the Republic of Tatarstan. For example, the probability of occurrence of this species in France was 39.7% (Maire et al., 2016), in Hungary 22% (Saly et al., 2011), in Lithuania 16% (Stakenas, 2002), in central France 13% (Pont et al., 2005), in northeastern Germany 12% (Fieseler and Wolter, 2006), but in the Udava River in Slovakia it is rare (Pekarik et al., 2011). In Romania it is a relatively spread species from the submontaneous lotic sectors to their end (Bănărescu, 1964) abundant in some of them like Târnava and Timiş rivers (Bănăduc, 2005; Bănăduc et al., 2013a), and rare in others like Iza, Cibin, and Olteţ rivers (Bănăduc, 1999, 2000, 2013b).

In some places, such as Romania common spirlin it is a relatively spread species in the Carpathian uper to middle lotic sectors (Bănărescu, 1964) abundant in some of the rivers like Târnava Mare and Olteţ rivers (Bănăduc, 2005; Bănăduc et al., 2013), France (Maire et al., 2016), and in the Udava River of Slovakia (Pekarik et al., 2011); elsewhere, such as in the Czech Republic, it is rare (Lusk and Pivnicka, 2009), also in Romania in Vişeu and Târnava Mică (Staicu et al., 1998; Bănăduc, 2005). In some river basins in Western Europe it is completely absent (Santoul et al. 2005; Fieseler and Wolter, 2006; Saly et al., 2011).

Such a difference in the probability of occurrence of bleak, common spirlin, and sunbleak between river basins in different parts of Europe may be due to phylogeographic characteristics, as well as genetic and ecological differences in the populations.

Distribution of bleak, common spirlin, and sunbleak in environmental gradients in small rivers of the Republic of Tatarstan. Relationship between fish species and environmental variables.

The probability of occurrence for each fish species had statistically significant relationships with three or more of the environmental variables (Tab. 1). The probability of occurrence of three species was associated with elevation, two species with the substrate and width of the river, and water velocity, forest cover, and river depth were associated with one species. The probabilities of occurrence of bleak and of sunbleak were associated with three environmental variables, and common spirlin with four variables (Tab. 1). All final models had satisfactory predictive power (AUC) varying from 0.784 to 0.888 (Tab. 1).

Table 1: Coefficients and model summary for models summarizing the relationship between presence/absence of fish and environmental variables. Species arranged in decreasing order of frequency.

Species	Constant	Cover	Ele-vation	Depth	Sub-stratum	Velocity	Width	AIC	AUC
Sunbleak	1.51	–	–8.36	–	–0.33	-1.69	–	378.4	0.784
Bleak	1.52	–1.14	-3.50	–	–	–	0.16	241.6	0.888
Common spirlin	–4.64	–	–2.11	1.99	0.69	–	4.13	155.6	0.845

The impact of elevation on populations and on individual fish species has been well studied in different parts of the world (Huet, 1959; Sanders and Rahbek, 2012; Carvajal-Quintero et al., 2015; Askeyev et al., 2017; Cheng et al., 2019; Ponomarev and Loskutova, 2020). In our current research, elevation had a significant negative effect on all fish species (Tab. 1). Figure 3 clearly illustrates the decrease probability of occurrences of all species in elevation gradient. The probability of occurrences of bleak and common spirlin was close to zero at elevations above 150 m (Fig. 3). These results once again confirm that elevation is the main environmental variable affecting fish species.

Common spirlin and bleak had increased probability of occurrence in wide rivers (Tab. 1). This species' preference for large rivers is noted in other parts of Europe (Kesminas and Vibrickas, 2000; Lusk and Pivnicka, 2009). Bleak avoids sites with a high forest cover (Tab. 1). This species prefers open sites; shading prevents this species from feeding effectively. In our study, sunbleak avoided sites of rivers with "hard" substrates (Tab. 1), since they are not suitable for this species as a substrate for spawning. Common spirlin had opposite preferences for substrate; its probability of occurrence increased in rivers with gravel and stones and great depths (Tab. 1). The common spirlin's preference for sandy-rocky substrates and relatively large depths is also noted in Târnava River watershed (Curtean-Bănăduc et al., 2019). Our studies have once again confirmed the fact that sunbleak, being a limnophil species, prefers areas with low velocity (Tab. 1). Human impact did not significantly affect the probability of occurrence for any of the selected species.

Higher probability of occurrences of sunbleak in comparison with bleak and common spirlin is associated with broader distribution by elevation and indifference to the width and depth gradients of the river, which allows this species to inhabit different sites of the rivers.

Species optimums and niche breadth

Table 2 shows the optimal points and breadths in the gradient of the environmental variables, which can be interpreted as the position of the realized niche and its width. Unfortunately, these optimum and niche ranges are not directly comparable with those in the literature because the latter were typically estimated using presence-absence data.

Comparing the optimum points between study species, we can say that they vary greatly (Tab. 2). For example, from sunbleak with an optimum point in altitude at 92.1 m, to bleak at 74.6 m. In contrast, in terms of river width (Tab. 2, Fig. 4), bleak had the largest optimum among the studied fish species, while sunbleak had the smallest, the difference between these species was more than 20 m (Tab. 2, Fig. 4). Common spirlin had the highest optimum of tree/bush cover and of water velocity. Sunbleak had an optimum to water velocity only half that of common spirlin (Tab. 2). The optimum points in depth for bleak and common spirlin were more than one m, while that for sunbleak was almost 0.5 m less than bleak (Tab. 2).

The width of the ecological niche between species was also significantly different in some variables (Tab. 2). The greatest difference between species was observed in river width (Fig. 4) and tree/bush cover. The niche breadth of sunbleak for river width was only 4.7 m, while common spirlin was 10.3 m, and bleak 18.3 m (Fig. 4). Bleak had the widest niche in four out of five environmental factors, which may explain its highest abundance among the selected fish species. But even within the same species, we see that there are strong differences in the values of the width of the ecological niche to different environmental factors. For example, common spirlin had the widest ecological niche in terms of tree/bush cover, while it has the narrowest in terms of elevation and river depth. This proves once again that the rational protection of various types of living organisms is perhaps satisfactorily carried out only when analyzing the effects of all environmental factors on occurrence and abundance.

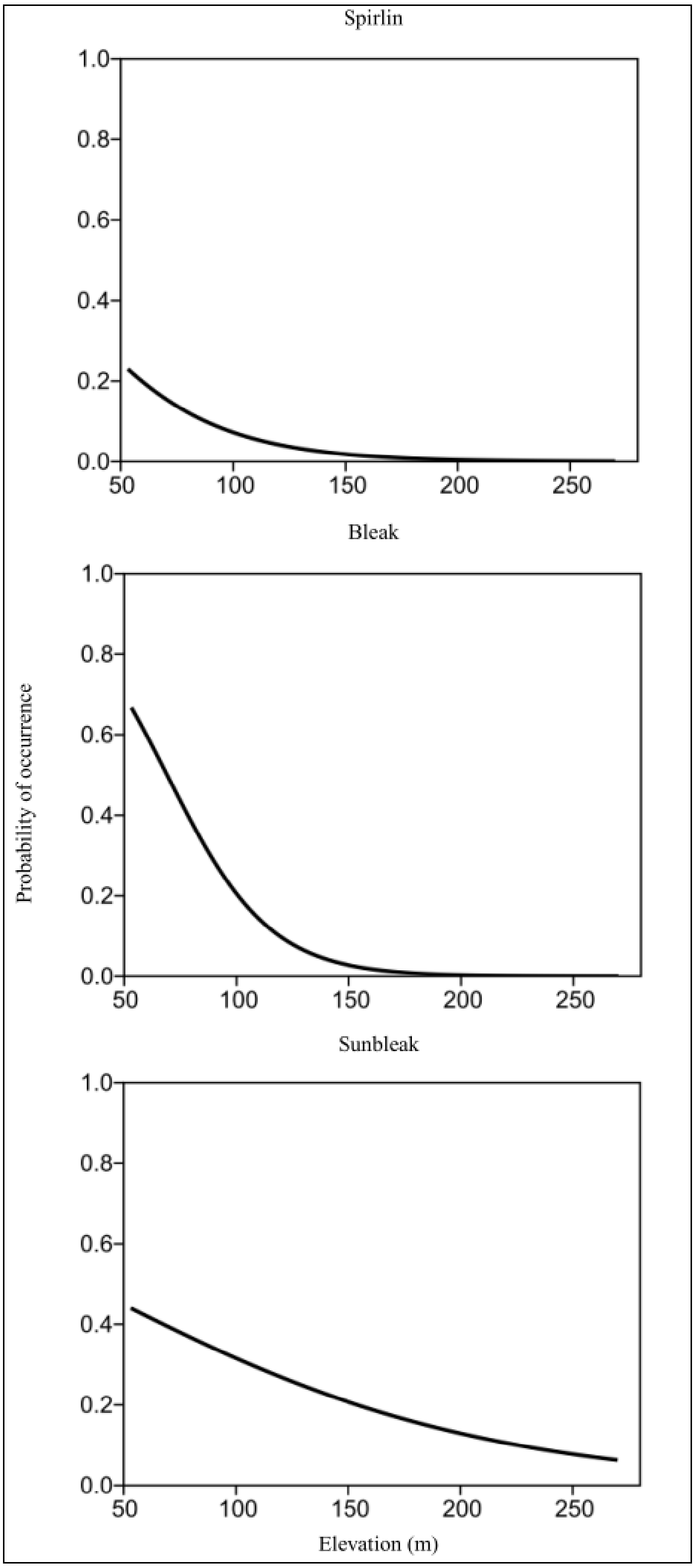

Figure 3: Relationship between the probability of occurrence of fish species and elevation.

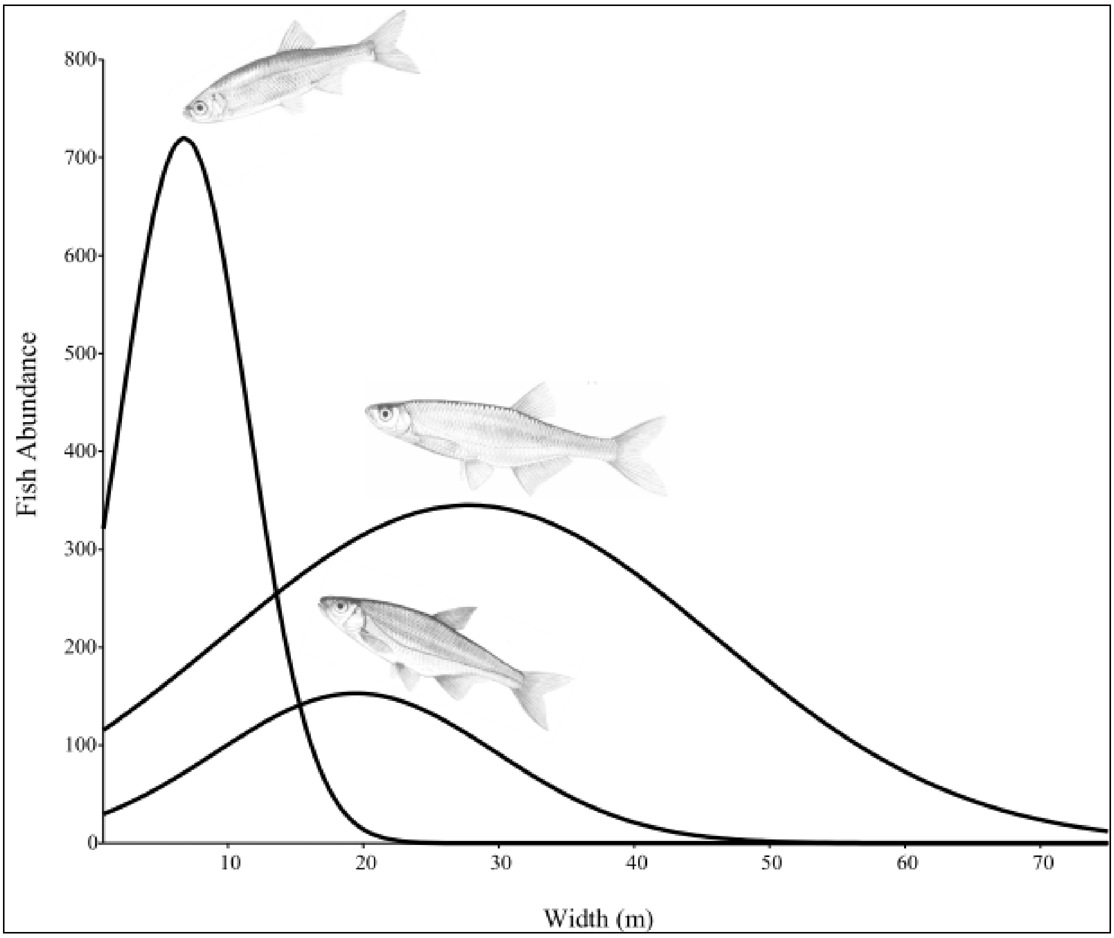

Figure 4: Distribution optimums and niche breadth of fish species by width of the river.

Table 2: Fish species optimum values and tolerance (niche breadth) against five environmental variables (based on abundance data).

Environmental factors	Bleak	Common spirlin	Sunbleak
Optimum values			
Elevation (m)	74.6	83.0	92.1
Width (m)	27.8	19.5	6.8
Cover tree/bush (%)	38.7	52.9	45.0
Velocity (m/s)	0.33	0.43	0.21
Depth (m)	1.15	1.06	0.67
Tolerance (niche breadth)			
Elevation (m)	18.6	13.4	15.7
Width (m)	18.3	10.3	4.7
Cover tree/bush (%)	21.8	35.2	19.0
Velocity (m/s)	0.14	0.12	0.10
Depth (m)	0.30	0.26	0.27

CONCLUSIONS

Our data, obtained on a large and heterogeneous territory in the east of the European continent, showed both differences and similarities in reaction models in relatively closely related fish species. Once again, the significant impact of the elevation gradient on the occurrence of different fish species has been shown. The state of the populations of the common spirlin – a rare and endangered species listed in the Red Data Book of the Republic of Tatarstan – does not cause serious concerns at this point in time in the study area. Small rivers are refugee for the preservation of the common spirlin. But the present climate change could have a serious negative impact on this rare fish. Therefore, further monitoring of the abundance and occurrence of the common spirlin should be carried out especially carefully. Based on the results of our work, a protected natural area was created, which includes a site of the river, which is characterized by a high abundance of the common spirlin.

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SOME ASPECTS OF THE GROWTH FEATURES AND CONDITION FACTOR OF *ARIUS GIGAS* (BOULENGER, 1911) FROM OBUAMA CREEK (RIVERS STATE, NIGERIA)

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KEYWORDS: length-frequency distributions, length-weight relationship, length-length relationship, Giant sea catfish.

ABSTRACT

Length-frequency distributions, length-weight relationships, length-length relationships and condition factors (Fulton's K_F, allometric K_A, and relative K_R) of *Arius gigas* in the Obuama Creek in Rivers State, Nigeria were investigated. 217 samples were collected from artisanal fishermen fishing on the Obuama Creek from March to September 2019. The parameter b of the length-weight relationship was 2.52 indicating negative allometric growth. The KF ranged from 0.51 to 2.03 with a mean value of 0.85 ± 0 while the overall low values of K_R and K_A in this study are generally a characteristic of fish in poor health. This study provides basic information on some of the biological features of *A. gigas* which should be useful for facilitating management strategies and regulations of the stocks.

RÉSUMÉ: Quelques aspects des caractéristiques de croissance et du facteur de condition d'*Arius gigas* (Boulenger, 1911) d'Obuama Creek (État de la Rivière, Nigéria).

Les distributions de fréquence de longueur, les relations longueur-poids, les relations longueur-longueur et les facteurs de condition (KF de Fulton, KA allométrique et relatif, KR) d'*Arius gigas* dans le ruisseau Obuama dans l'État de la Rivère, au Nigeria, ont été étudiés. De mars à septembre 2019, 217 échantillons ont été prélevés avec l'aide des pêcheurs artisanaux qui pêchent dans le ruisseau Obuama. Le paramètre b de la relation longueur-poids était de 2,52 indiquant une croissance allométrique négative. Le KF variait de 0,51 à 2,03 avec une valeur moyenne de 0,85 ± 0, tandis que les valeurs globales et faibles de KR et de KA dans cette étude sont généralement caractéristiques des poissons en mauvaise santé. Cette étude fournit des renseignements de base sur certaines des caractéristiques biologiques de l'*A. gigas* qui devraient être utiles pour faciliter les stratégies de gestion et la réglementation des stocks.

REZUMAT: Unele aspecte ale caracteristicilor de dezvoltare și indicele ponderal la *Arius gigas* (Boulenger, 1911) din Pârâul Obuama (Statul Râurilor, Nigeria).

Distribuțiile lungime-frecvență, relațiile lungime-greutate, relațiile lungime-lungime și factorii de condiție (K_F al lui Fulton, K_A alometric și relativ K_R) ai lui *Arius gigas* în Pârâul Obuama din Statul Râurilor, Nigeria au fost investigați. 217 probe au fost colectate de la pescari artizanali care își desfășoară activitatea în Pârâul Obuama în martie-septembrie 2019. Parametrul b al relației lungime-greutate a fost de 2.52 indicând o creștere alometrică negativă. K_F a variat de la 0.51 la 2.03, cu o valoare medie de 0.85 ± 0, iar valorile globale scăzute ale K_R și K_A din acest studiu sunt, în general, caracteristice peștilor cu o sănătate precară. Acest studiu oferă informații de bază cu privire la unele dintre caracteristicile biologice ale *A. gigas*, care trebuie să fie utile pentru facilitarea strategiilor de gestionare și reglementare a stocurilor.

INTRODUCTION

The majority of Ariidae fish, which are known as marine catfish, inhabit shallow coastal areas and estuaries in tropical and temperate regions. A restricted number of species is either entirely confined to marine waters where they can be found at depths of 150 m or to freshwaters in the upper tributaries of rivers 500 km away from their river-mouths. (Marceniuk and Menzes, 2007) This family has 30 genera and 143 species; the genus *Arius* has 27 species (Froese and Pauly, 2011). Out of the four species recorded in the Gulf of Guinea, three species are found in the Nigerian freshwaters, these are *Arius gigas*, *Arius lutiscutatus*, and *Arius heudeloti* (Schneider, 1990; Adesulu and Sydenham, 2007).

The giant sea catfish (*Arius gigas*) is of commercial significance as a food fish and one of the dominant species in the Nigerian Industrial coastal fisheries; however, it's population has declined due to overfishing and possibly chemical pollution from the outcome of these factors, the IUCN red list currently lists the species as Data Deficient (IUCN, 2019). According to the National Bureau of Statistics (2017), fish production by species in Nigerian waters from 2010 to 2015 showed a steady increase in the sea catfish from 2010 (17,236 tons) to 2014 (23,854 tons) and then declined sharply in 2015 to 17,444 tons.

The studies on growth are components of fish stocks management and are used to characterize the state of fish populations. For example, relations between total and standard lengths of fish are important in management for comparative growth studies (Sandoval-Huerta et al., 2014). Information generated from length-weight relations can also be used to assess fish conditions and fish growth patterns, whether isometric or allometric (Pope and Kruse, 2001; Hashim et al., 2017), based on the assumption that heavier fish of a given length are in better condition (Pope and Kruse, 2001; Sandoval-Huerta et al., 2014; Hashim et al., 2017).

Information on the length-weight relationship and condition factor of *A. gigas* inhabiting the Nigerian water is very scarce and incomplete (IUCN, 2019). Thus, the goal of this study was to assess the length-frequency distributions (LFDs), length-weight relationships (LWRs), length-length relationships (LLRs), and condition factors (allometric, K_A, Fulton's, K_F and relative, K_R) of *Arius gigas* from the Obuama Creek, Rivers State, Nigeria, so as to provide background information for it's conservation and better management.

MATERIAL AND METHODS

The study was conducted in Obuama Creek (Fig. 1) a tributary of the Sombrero River, in Rivers State, Nigeria. A freshwater system whose waters originate from outside or wholly within the lowlands of the coast and which experiences tidal effects as manifested in many species of marine fish. Rivers State features a tropical monsoon climate with lengthy and heavy rainy seasons and very short dry seasons. The dry season is between November and March and the wet season is from April to November. In the wet season, annual rainfall is between 49.5 mm in January and 580 mm in July and is usually interrupted by a short dry spell in August. The average temperature ranged from 27.1°C to 31.1°C.

Monthly fish samples were collected at random (once a month) from the local fishermen using beach seine nets of various mesh sizes (stretched) ranging between two and 19 cm from March to September 2019. Specimens were taken from two major landing sites along the creek. Station 1 (Mission Poku) is situated between 04°48.004' North latitude and 006°46.565' East longitude, while station 2 (Erimia Poku) is situated between 04°48.033' North latitudes and 006°46.523' East longitude (Fig. 1). These two sites are considered representative sampling sites due to the routine landing of *A. gigas* caught by beach seine. A total of 109 and 108 fish samples were recorded in station 1 and station 2, respectively.

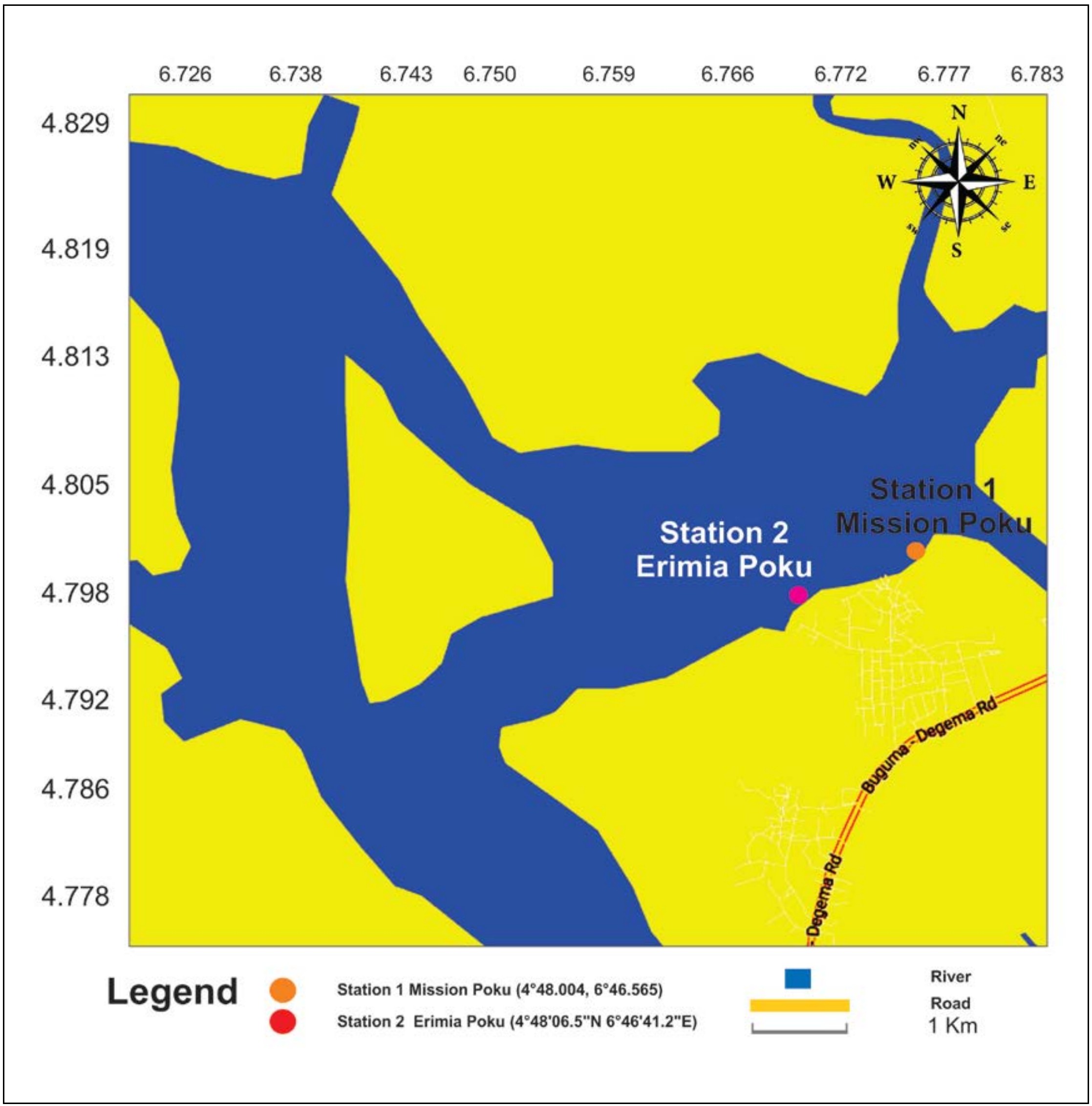

Figure 1: Map of the study area showing the sampling stations on Obuama Creek, Nigeria.

Fresh samples (dead fish) were immediately chilled in ice on site and fixed with 10% alcohol upon arrival in the Fisheries Laboratory f University of Port Harcourt, Nigeria for proper identification using the keys constructed by Schneider (1990) and Adesulu and Sydenham (2007). After cleaning and washing the specimens, total length (TL), fork length (FL) and standard length (SL) were recorded to the nearest 0.1 cm, and weight (W) was measured with a precision balance (0.01 g).

The length-weight relationships were calculated using the equation $W = aL^b$, where W: body weight (g), L: fish length (TL, cm), *a*: regression constant and *b*: regression co-efficient (Le Cren, 1951). The length-length relationships were estimated by the simple linear regression: $Y = a + bX$, where Y: various body lengths, X: total length, a: proportionality constant, and b: regression coefficient (Zar, 1996).

The condition factor (K_F) was calculated according to the formula by Fulton (Froese, 2006) as follow: $K_F = 100 \cdot W/L^3$, where W: body weight (g) and L: fish length (TL, cm). The relative condition factor (K_R) for each individual was calculated using the formula by Le Cren (1951): $K_R = W/(a \cdot L^b)$, where W = body weight, L = total length, a and b = LWR parameters. The allometric condition factor (K_A) was calculated using the formula by Tesch (1968): $K_A = W/L^b$, where W = body weight and L = total length and b = LWR parameter. The condition factors from the two stations were quantified using t-test.

RESULTS AND DISSCUSION

The total length ranged from 17 to 39 cm with a mean value of 26.91 ± 4.57 cm and the body weight ranged between 40 and 556 g with a mean value of 174.25 ± 90.62 g. The mean values for fork length, standard length and weight of liver weight were 21.40 ± 4.00 cm, 19.41 ± 3.80 cm, and 1.96 ± 1.20 g respectively. The size of *A. gigas* in the present study (17 to 39 cm) was similar to the findings of Abohweyere (2011) who reported that the total length of *A. gigas* ranged from 15-42 cm in Sombreiro River and Creek. However, the size of the species in the present study was lower than in Taylor (1986) who reported a maximum length of 165 cm. This may be related to differences among fishing gear used, and too different of ecological condition of these habitats.

Descriptive values of the length (cm) and weight (g) measurements (TL, FL, SL, W, and LW) are presented in table 1. The TL-frequency distribution showed that the maximum population stands on 25 cm TL size group and dominant length groups were 25 to 29 cm (Fig. 2). Length-frequency distributions provide a vision to help understand when the fishing pressure starts and ends (Khan and Khan, 2014). In this study, the variation in fish size (length-frequency) indicated that the fish population ranged from immature specimens to fully matured ones with the majority of fish captured by the fishermen in the category of immature or small individuals. This means that the Obuama Creek could be characterized as nursery ground. This is in agreement with Little et al. (1988), who noted that creeks serve as a nursery ground, in which fingerlings are developed. Nevertheless, their large-scale exploitation has resulted in mass destruction of the stock. Heavy fishing produces a population of mainly young small individuals, since the fish are caught as they reach a catchable size and before spawning, so that reproduction capacity of the stock is seriously impaired and where adult survival is lower, the fish begin reproduction at an earlier age and invest a greater proportion of their energy budget into reproduction (Molles, 2010). Therefore, there is a need for regulations requiring a minimum legal size of the fish caught as a conservation measure for *A. gigas*. The minimum mesh size used by the fishermen ranged from two cm and the maximum size was 19 cm in the study area. By increasing the minimum mesh size to from two to 7.5 cm, it will reduce juvenile fish being caught and allow the fish mature and reproduce before they are captured. The mesh size (7.5 cm) was recommended as the standard as minimum mesh size for all inland water bodies in Nigeria. However, in the absence of effective regulations, all native communities in Nigeria have customary laws on water rights. For example, community regulations stipulate who should fish where, when, and with what fishing gear in a river. Other measures include closure of areas, of seasons, ban on taking small fish, and provisions allowing a portion of catch to escape. So, devolution of the resources and allocation decisions to the local fishers will often be the most effective way of resolving uncertainties and improving management (Bailey, 1982). It would be far easier, more effective and less costly. However, in the last few decades, fishing communities in Nigeria have been fragmented as a result of civil unrest and have found it difficult to survive and operate as unit as a result of continuous conflicts in rural areas. Integrating and mobilizing fishermen to manage the fish is the only solution.

Table 1: Descriptive statistics on the length (cm) and weight (g) measurements of the *Arius gigas* in the Obuama Creek, Nigeria; n, sample size; TL, total length; SL, standard length; CL, confidence limit for mean values.

Measurement	N	Min	Max	Mean + SD	$CL_{95\%}$
Body weight (g)	217	40	556	174.25 ± 90.62	162.13 – 186.38
Total Length (cm)	217	17	39	26.91 ± 4.57	26.30 – 27.52
Fork Length (cm)	217	13	33	21.40 ± 4.00	20.87 – 21.94
Standard Length (cm)	217	12	30.2	19.41 ± 3.80	18.90 – 19.92
Weight of liver (g)	217	0.34	6.4	1.96 ± 1.20	1.80 – 2.12

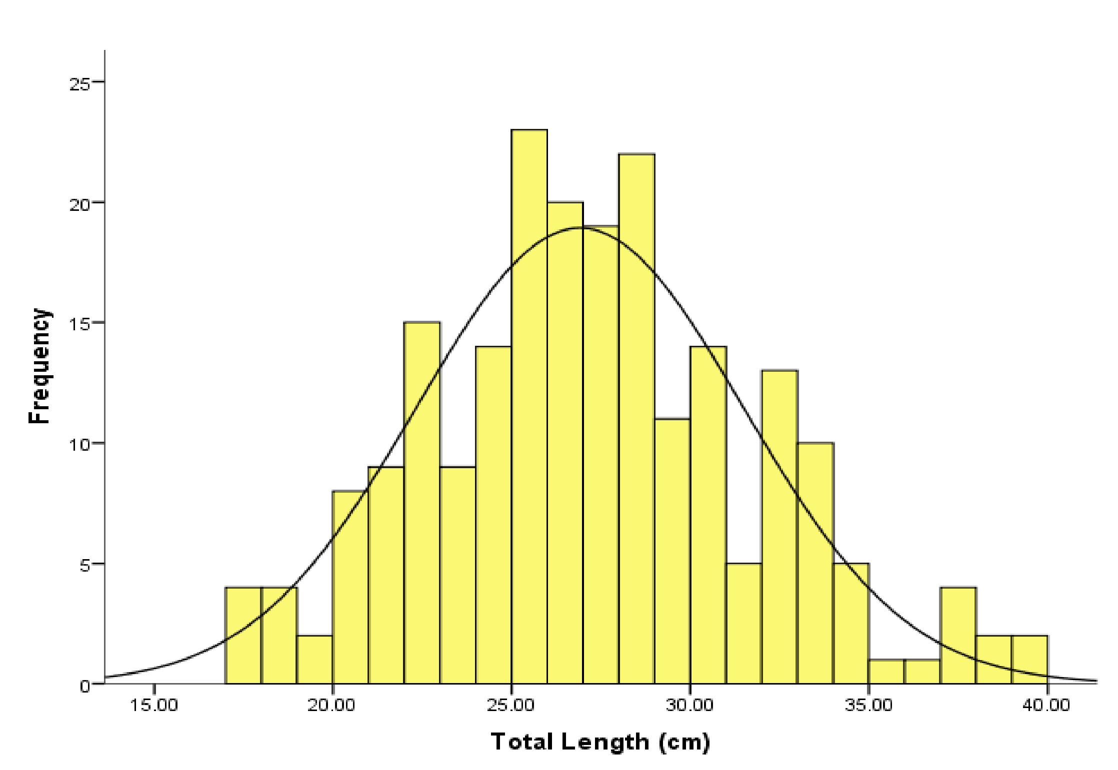

Figure 2: Total length distribution frequency of *Arius gigas* in the Obuama Creek, Nigeria.

The regression parameters (*a* and *b*) and their 95% CL in the LWRs, co-efficient of determination (r^2) and growth type of *A. gigas* are shown in table 2 and figure 3. The exponential value of length-weight relationships '*b*' was 2.52 for the TL vs. W, 2.34 for the FL vs W and 2.22 for SL vs. W (Tab. 2) all which indicated negative allometric growth. The b value in this study falls between two and four and are close to three that are usually obtained for fishes (Tesch, 1968). By negative allometry ($b < 3$), the fish is said to be "lighter for its length" as it grows (Froese, 2006). The b parameter of the length-weight relations of fishes is affected by a number of factors, including environmental conditions (such as temperature and salinity), sex, gonad maturity, health, season, habitat, nutrition, area, degree of stomach fullness, differences in the length range of the caught specimen, and the fishing gear used (Tesch, 1971; Froese 2006).

Table 2: Descriptive statistics and estimated parameters of the length-weight relationships (BW = a × Lb) with 95% confidence limits and **–** A negative allometric growth types of *Arius gigas* in the Obuama Creek, Nigeria; TL, total length; FL, fork length, W, body weight; K_A, allometric.

Equation	a	b	CL95% of *a*	CL95% of *b*	r^2
$BW = a \times TL^b$	–3.21	2.52	–6.98 – –0.05	1.58 – 3.64	0.79
$BW = a \times FL^b$	–2.10	2.34	–2.99 – –1.8433	2.33 – 2.57	0.80
$BW = a \times SL^b$	–1.50	2.22	–2.67 – –0.79	1.99 – 2.62	0.79

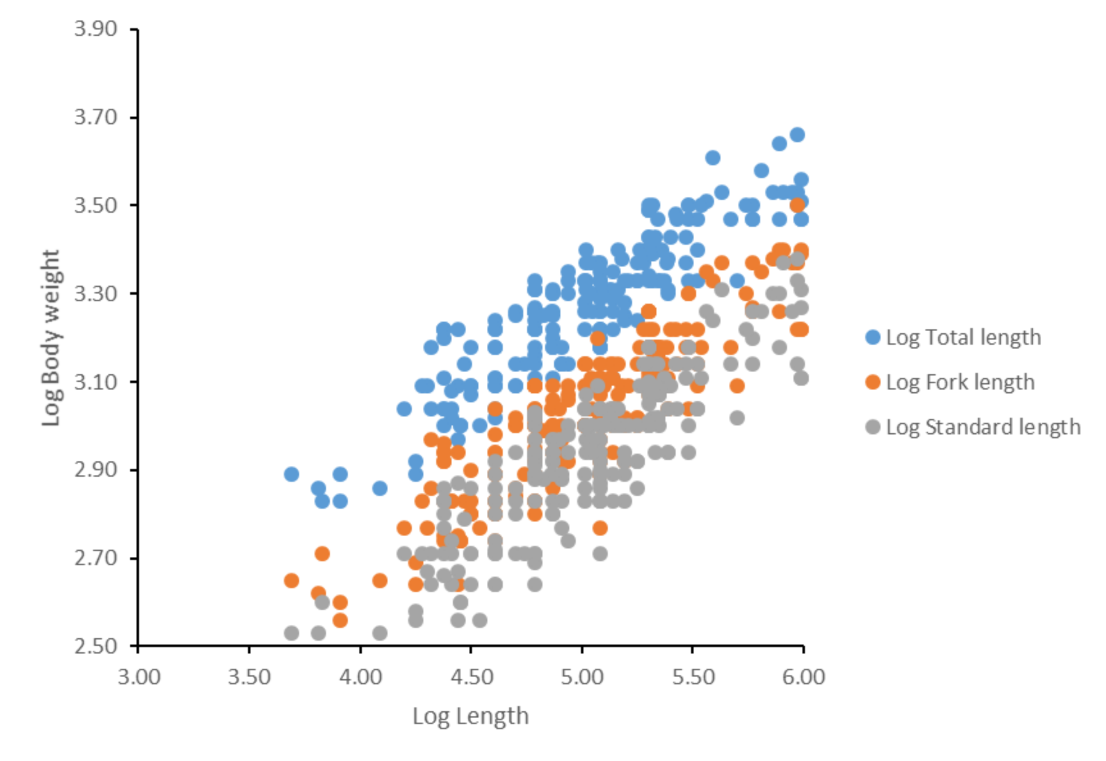

Figure 3: Relationship between the body weight with the total length, fork length, and standard length of *Arius gigas* in the Obuama Creek, Nigeria.

Furthermore, results of the length-length relationships (SL vs. TL, TL vs FL, and SL vs FL) of *A. gigas* are presented in table 3 with the regression parameters (a and b) of the LLRs and, co-efficient of determinations (r^2). The calculated b value was 1.05 for SL vs. TL with the r^2 value of 0.86 and SL vs FL the b value was 1.02 and r^2 value was 0.95 while TL vs FL, the b value was 0.87 and r^2 was 0.89. LLR is important in fisheries management for comparative growth studies (Moutopoulos and Stergiou, 2002). In this study, the b value of length-length relationships for SL vs. TL, TL vs FL and SL vs FL were 1.05, 1.02 and 0.87 respectively indicating allometric growth *A. gigas* in the Obuama Creek. The results were lower than the minimum and maximum b values of 1.2 and 1.3 respectively reported by Fishbase (2019). The corresponding significant correlation coefficients (r^2) indicating a length-weight relationships (in log scale) are strongly linear in all the cases.

Table 3: Descriptive statistics and estimated parameters on the length-length relationships of *Arius gigas* in the Obuama Creek, Nigeria; TL, total length; FL fork length, SL, standard length; a, intercept; b, slope ; r^2, coefficient of determination.

Equation	a	b	r^2
SL = a + bTL	–0.50	1.05	0.86
SL = a + bFL	–0.16	1.02	0.95
TL = a + bFL	0.62	0.87	0.89

The condition factor K_F ranged from 0.51 to 2.03 with a mean value of 0.85 (± 0.22) close to the standard threshold of one, indicating that the species were in good condition. Carlander (1950) identified K_F as a sensitive measure of changes and differences in body form. According to Ricker (1975) condition factor below 0.7 is considered to be low, and above 0.9 is high, the larger the factor the better the condition. This study postulates that the K_F is the best biometric index for assessing the well-being of this species in the study area with values ranging from 0.51 to 2.03 and a mean value of 0.85 ± 0.22. Koivogui et al. (2020) reported lower values of 0.40 ± 0.04 to 0.68 ± 0.05 and 0.33 ± 0.04 to 0.50 ± 0.06 for male and female *A. gigas* respectively from the bays of Tabounsou and Sangareah in Republic of Guinea. The condition factor in the lifetime of fish may vary with change depending on various factors such as climatic condition, locations, time, and stages of development (Blackweel et al., 2000). Due to differences in environmental conditions, between systems different fish populations display different levels of condition according to exploitation pressure such as quality and type of fishing gears, level of fishing efforts, food availability, or catchment characteristics (Boys et al., 2012).

Monthly variations of K_F showed that the lowest value (0.73) was recorded in September and the highest value (2.03) in June (Fig. 4). The monthly variations in condition factors could be attributed to various reasons such as changes in environmental factors with time (i.e. water quality), availability of natural food supply, physiological condition (i.e. accumulation of fat and gonads development) (Jennings et al., 2001) and stage of maturity (Khallaf et al., 2003). The higher condition recorded in June could be attributed to good water quality and an abundance of food in the study area due to the highest rainfall in the month. The condition factor is a quantitative indicator of individual wellbeing reflecting recent food availability conditions (Le Cren, 1951). According to several researchers, many tropical fish were reported to breed at the beginning of the rainy season due to the large varieties of food items (Marsh et al., 1986).

Monthly variations of K_F showed that the lowest value (0.73) was recorded in September and the highest value (2.03) in June (Tab. 4). In this study, K_R was studied in order to evaluate the health and productivity of *A. gigas* in the Obuama Creek. According to Le Cren (1951) the value of K_R higher than one indicates good health and less than one indicates relatively poor condition of the fish. The mean value for K_F as shown in table 5 below in station 1 was 0.83 ± 0.02, while that of station 2 was 0.90 ± 0.03. The t test indicates that there was no significant relationship between the two stations (t = –2.32 = P < 0.16) (Tab. 5). The overall, low values of K_R and K_A in this study are generally characteristic of fish in poor health. However, low values of K_R and K_A could be attributed to the fact that the morphometric condition indices may have a limited sensitivity, and provide a rapid, non-invasive measurement of the physiological status of the fish (Brown and Murphy 1991; Neumann and Murphy, 1991).

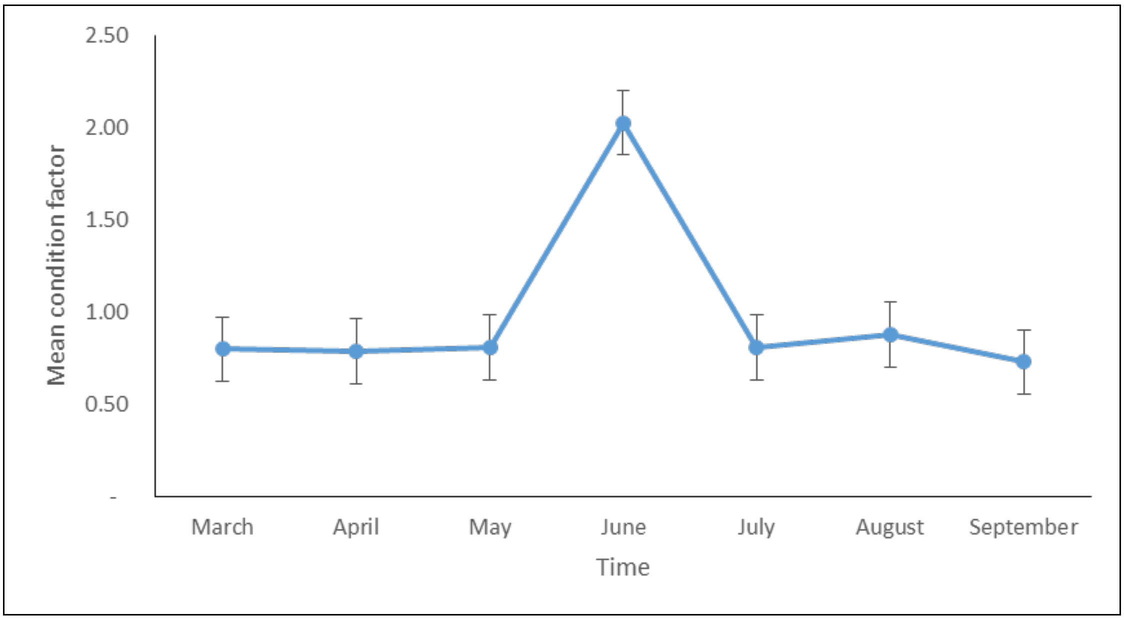

Figure 4: Monthly fluctuation of Fulton's condition factor of *Arius gigas* in the Obuama Creek, Nigeria.

Table 4: Descriptive statistics and condition factors measurements and their 95% confidence limits of the *Arius gigas* in the Obuama Creek, Nigeria; allometric condition factor; K_A; K_F; Fulton's condition factor; K_R, relative condition factor values; CL, confidence limit; P, shows the level of significance.

Condition factors	N	Min	Max	Mean ± SD	$CL_{95\%}$
K_F	217	0.51	2.03	0.85 ± 0.22	0.82 – 0.88
K_R	217	0.60	1.13	0.61 ± 0.11	0.55 – 0.61
K_A	217	0.52	0.71	0.54 ± 0.31	0.04 – 0.54

Table 5: Comparisons between conditions factors of *Arius gigas* in the two stations in the Obuama Creek, Nigeria; allometric condition factor; K_AK_F; Fulton's condition factor; K_R, Relative condition factor.

	Station 1	Station 2	t-value	p-value	Decision
K_F	0.83 ± 0.02	0.90 ± 0.03	–2.32	0.16	NS
K_R	0.61 ± 0.03	0.70 ± 0.01	–2.22	0.18	NS
K_A	0.57 ± 0.01	0.64 ± 0.02	–2.10	0.15	NS

CONCLUSIONS

This study provides important data on the length frequency distributions length-weight relationship, length-length relationships, and condition factors of *Arius gigas* from Obuama Creek which should be useful in facilitating management strategies and regulations for the sustainable conservation of the fish stocks of this species.

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A STUDY ON MARINE FISHERY RESOURCES OF ANDHRA PRADESH: ECOLOGICAL ASPECTS AND MORPHOMETRICS OF COMMON MARINE FISHES OF VISAKHAPATNAM – PROTEIN CONTENT AND BIOACCUMULATION OF HEAVY METALS IN POMFRET FISH SPECIES

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KEYWORDS: marine fish, morphometrics, protein content, heavy metal pollution.

ABSTRACT

212 marine fishery resources were recorded in the waters of Andhra Pradesh State. Morphometric data was provided for 20 edible fishery resources landing at the fishing harbour of Visakhapatnam. The harbour area is polluted due to influx of various industrial effluents and domestic sewage. In *Pampus argenteus, P. chinensis* and *Parastromateus niger*, the total protein content is 16.24-19.58%. Further, arsenic concentration in muscle and gill portions individually or combined in all three of the species is highly negligible. Cadmium, mercury, and lead levels in the muscle and gills of these species are within or slightly above the recommended limits set by EU (2006) and FAO (2003), FAO/WHO (2011), MAFF, and FSSAI (2011) indicating that the consumption of these fishes is not harmful.

ZUSAMMENFASSUNG: Untersuchung der Meeresfischerei Ressourcen von Andhra Pradesh: ökologische Aspekte und morphometrische Angaben zu verbreiteten Meeresfischen des Visakhapatnam – Eiweißgehalt und Bioakkumulation von Schwermetallen in Pomfret Fischen.

In den Meeresbereichen des Bundesstaates Andhra Pradesh, wurden insgesamt 212 fischereiressourcen erfasst. Für 20 essbare Arten aus den fischereiressourcen, die im Fischereihafen von Visakhapatnam anlanden, wurden morphometrische Daten erfasst. Das Hafengebiet ist durch den Zufluss verschiedener Industrie- und häuslicher Abwässer dauernd verschmutzt. Bei *Pampus argenteus*, *P. chinensis* und Parastromateus niger beträgt der Gesamtproteingehalt 16,24-19,58%. Auch ist die Arsenkonzentration in Muskel- und Kiemenanteilen einzeln oder in Kombination bei allen drei Arten sehr vernachlässigbar. Die Cadmium-, Quecksilber- und Bleiwerte in den Muskeln und Kiemen dieser Arten liegen innerhalb oder geringfügig über den von der EU (2006) und FAO (2003), FAO/WHO (2011), MAFF und FSSAI (2011) festgelegten Grenzwerten, was darauf hindeutet, dass der Verzehr dieser Fische nicht schädlich ist.

REZUMAT: Un studiu asupra resurselor piscicole marine din Andhra Pradesh: aspecte ecologice și morfometrice ale speciilor comune de pești marini din Visakhapatnam – conținutul proteic și bioacumularea de metale grele la speciile familiei Bramidae.

212 resurse piscicole au fost înregistrate în apele marine ale statului Andhra Pradesh. Au fost furnizate date morfometrice pentru 20 de resurse piscicole comestibile din portul Visakhapatnam. Zona portuară este poluată de efluenți industriali și ape uzate menajere. În *Pampus argenteus*, *P. chinensis* și *Parastromateus niger*, conținutul total de proteine este între 16.24-19.58%. Concentrația de arsenic în mușchi și branhii în toate speciile este neglijabilă. Nivelurile de cadmiu, mercur și plumb din mușchii și branhiile acestor specii se încadrează sau depășesc ușor limitele recomandate stabilite de UE (2006) și FAO (2003), FAO/OMS (2011), MAFF și FSSAI (2011), indicând faptul că consumul acestor pești nu este dăunător.

INTRODUCTION

Phenotypic plasticity is important for fishes to respond adaptively to environmental changes by modification in their physiology and behaviour which in turn bring about changes in their morphology, reproduction or survival that mitigate the effects of environmental variation (Truman, 1999). The phenotype of an individual is largely unresponsive to fluctuating environmental conditions and is easily quantified while behavioural and physiological characters respond quickly to local conditions but fluctuate greatly during an individual's life-span (Rutherford et al., 1987; Crowl and Covich, 1990). Measurements of length-weight relationships are useful for the prediction of weight from length values, condition of fish, stock assessment, and estimation of biomass (Petrakis and Stergiou, 1995; Vaslet et al., 2007). Further, length-weight relationships also provide information about the stock composition, growth, life span, production, and mortality (Stergiou and Moutopoulos, 2001). Phenotypic features of fishes such as total length, standard length, head length, depth of the body and weight, are important for use as a valid method to identify the specimens of fish collected with their systematic morphology (Karunanidhi et al., 2017).

Fishes have been recognized as good accumulators of organic and inorganic pollutants (Gado and Midany, 2003; Curtean-Bănăduc et al., 2020). Age of fish, lipid content in the tissue, and mode of feeding are important factors that affect the accumulation of heavy metals in fishes. Fish diagnoses are often used to detect and monitor these heavy metal contaminations in aquatic ecosystems (Nadal et al. 2004; Kar et al., 2008). Heavy metals concentration of aquatic habitats has increased due to intense anthropogenic activities in recent years. Because of this condition, aquatic organisms are exposed to elevated levels of metals, which threaten the health of aquatic organisms as well as humans. Heavy metal accumulation levels in fishes from various aquatic environments have been widely reported (Zubcov et al., 2008; Khoshnood and Khoshnood, 2013; Taiwo et al., 2019). Fishes with heavy metal accumulation levels exceeding the stipulated limits if consumed by humans, then these metals may induce many health problems (Yilmaz, 2003; Papagiannis et al., 2004; Dalman et al., 2006). Fishes through respiration, adsorption, and ingestion can accumulate metals. The feeding habits and the rate of resorption are also important factors in metal accumulation. Benthic fish species have higher metal levels than pelagic species as the metal accumulation of sediments and detritus are many times higher than living organisms and water. Since the biological and ecological demands of fishes are different, the metal concentration levels of species are also different accordingly. Metal accumulation ratios of species depend on the water environment in which they are caught, season, and their trophic levels, sexes, and sizes. (Atlindag and Yigit, 2005; Yilmaz and Yilmaz, 2007) Metal concentration levels among various tissues and organs of the same species are also different. Metal accumulation capacity of muscle of fishes is lower than other tissues and organs such as skin, gill, intestine, and liver (Dural et al., 2007). Heavy metal levels in a fish are related to its living environment, feeding behaviour, and foraging habitats (Yi and Zhang, 2012; Rajeshkumar et al., 2018;). Some studies have suggested that the foraging habitat is a strong predictor for variations in heavy metal concentrations in fish (Goutte et al., 2015). Freshwater fishes tend to accumulate heavy metals in their organs more than marine fishes. The reason for such a difference between the two types of habitats is that freshwater fishes tend to lose salts and gain water. On the other hand, marine fishes tend to gain salts and lose water (Nikinmaa, 2014). Heavy metals are important due to their toxicity and ability to bioaccumulate in aquatic habitats and organisms (Miller et al., 2002; Astratinei and Varduca, 2008; Iepure and Selescu, 2009; Aziz et al., 2011; Akköz, 2016). Heavy metals tend to accumulate in the aquatic environment because they cannot be degraded, this leads to environmental problems and human exposure (Donati, 2018).

Fish is a very important food source for humans, providing essential fatty acids like omega-3, proteins, vitamins, and minerals. Despite its nutritive value, its consumption brings an abundance of potential hazards for humans (Gado and Midany, 2003). Fish is at the top of the aquatic food chains and can accumulate large amounts of toxic elements like heavy metals (i.e. lead, mercury, cadmium, chromium, and arsenic) which can induce death when they concentrate too much in organisms' body. They have the tendency to accumulate in various organs and muscle tissue of fish. Contaminated fish enters the human body through consumption and causes health hazards (Nwabunike, 2016). Some heavy metals (i.e. mercury, cadmium, and lead) are toxic to fishes even at low concentrations, whereas others (i.e. zinc, copper, and cobalt) are biologically essential but become toxic at high concentrations (Amundsen et al., 1997). Some heavy metals such as arsenic, cadmium, lead, and mercury are of major environmental concern as they can cause severe health implications for humans and other living organisms. Moreover, some elements such as chromium, nickel, copper, and zinc that play essential roles in life activities become toxic in excess amounts (Huang et al., 2019).

Fish faunal diversity relates to genotypes with fish populations to species within a fish community to species across water regimes (Burton et al. 1992) and constitute a half of the total number of vertebrates in the entire world. About 2,500 species out of approximately a total of 22,000 fish species have been reported to be found in India. Of these, 1,570 species occur in marine waters (Jayaram 1999; Kar 2007, 2013, 2019). However, edible fish species inventory in each Indian State is not accurate. Since the inventory for the marine fish species of the coastline of Andhra Pradesh State is not available, there is an urgent need for this. Further, Visakhapatnam City has a coastline that extends about 132 km and has significant economic activity yielding out of the fishermen population associated with fishing activity. The area is polluted due to fast growing urbanization, industrialization, and tourism activities. Fishes caught from the coastal waters are sold in local fish markets regularly. But, there is no record of fish species that are common and commercially important and this situation warrants documenting the common and commercially important fish species sold in the local markets.

With this backdrop, the inventory of edible marine fish species in the study area and some common and commercially important edible marine fish species landing at Visakhapatnam Fishing Harbour/local fish markets have been separately provided. The ecological characters (biotype complex and feeding habitat) and morphological characters (total length/mantle length, standard length, head length, body depth, and weight) for all edible marine fish species landing at Visakhapatnam Fishing Harbour/local fish markets have been noted. The price (low, medium, and high) and importance (commercial/non-commercial) for each fish species have also been noted. Gears used for capturing the fishes that are captured from Visakhapatnam coast have been provided. The edible marine fish species exported through the Visakhapatnam Sea Food Export Trade Center have been listed along with the fish load exported by each exporting company. Further, protein content in muscle portion and heavy metals (cadmium, lead, mercury, and arsenic) in muscle and gill portions of three fish species, *Pampus argenteus* (Euphrasen, 1788), *P. chinensis* (Euphrasen 1788) (Stromateidae) and *Parastromateus niger* (Bloch, 1795) (Carangidae) collected from the Visakhapatnam Fishing Harbor have been assessed. These fish species are consumed by the inhabitants living in and around the study area. The assessment of heavy metals is important to understand the risks of fish contaminated with these metals on human health. Therefore, this knowledge is imperative to create awareness among consumers of these fishes and to monitor heavy metal concentrations regularly to control marine pollution and reduce its impact on human health.

MATERIAL AND METHODS

Study area

The State of Andhra Pradesh, India, lies between 12°41' and 19.07°N latitude and 77° and 84°40'E longitude. It has a vast coastline which is a source of marine fishery resources that sustain local fishing communities by providing livelihood and provide seafood for most of the population in this State. Visakhapatnam (17.6868°N latitude and 83.2185°E longitude) is an important coastal belt that runs to more than 130 km and serves as a center for vibrant economic activity due to availability of various marine fishery resources and the dependence of fishermen on fishing activity for their livelihood. This place hosts a natural harbor and port which serves as a seat for local fish markets where edible marine fishes, crustaceans, and molluscans caught from the coastal waters are sold regularly. Further, it hosts busy shipping activities and a number of large and small scale industries. Coastal waters of Visakhapatnam are consistently polluted with treated and untreated industrial effluents, domestic sewage, material leakages despite the best efforts put in place by port and some industrial units.

Inventory of marine fishery resources of Andhra Pradesh

Field visits to different locations of coastal areas of Andhra Pradesh were made during 2018-2020 to record the marine species collected from coastal waters and sold in local fish markets. For this, personal visits were made to local fish markets to record the marine fishes sold locally. Further, secondary information available from Fisheries Department of Andhra Pradesh was also collected. Based on field and secondary information, an inventory of marine fishery resources was prepared for the entire state of Andhra Pradesh. In this inventory, the marine species were categorized into fishes, crustaceans, and molluscans, and accordingly the species were listed.

Common edible marine species landing/sold at Fishing Harbour and local fish markets of Visakhapatnam

Field visits to the fishing harbour and local fish markets were made at different times of the year during 2018-2020 to record the common edible fishes and molluscans collected from coastal waters of Visakhapatnam. The marine species were recorded family-wise and then their status was mentioned according to IUCN Red list.

Habitat, migration type, feeding habit, local and export value, and price value of common edible marine species landing/sold at Fishing Harbour and local fish markets of Visakhapatnam

Based on field visits, local fisheries department and secondary information from literature, habitat, migration type, feeding habit were provided for the fish and molluscan species sold at fishing harbour and local fish markets. Further, personal interviews with fishermen were conducted to elicit information on local and export value and price value of all these species. The information thus collected was recorded species-wise. This information was used to evaluate the importance of the habitat, migration type and feeding resources in enabling these species on a sustainable basis. Further, the information on the fish species exported and the price value were used to understand the importance of such species for providing livelihood, employment, and foreign exchange. The companies engaged in the export of commercially important marine species through the Sea Food Export Trade Center were noted. The quantity of each marine species exported (Mean and Standard Deviation) by each company once every 15 days was also recorded to know the value of exported species.

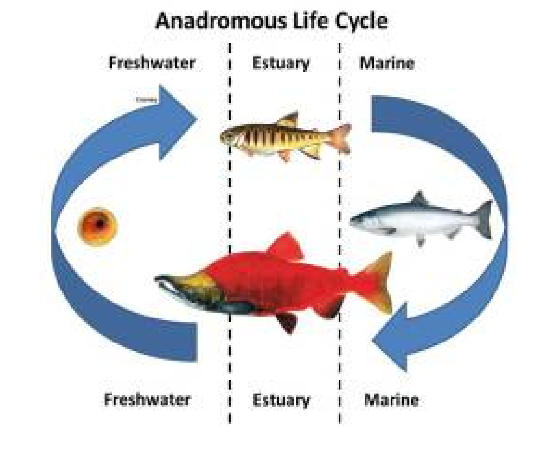
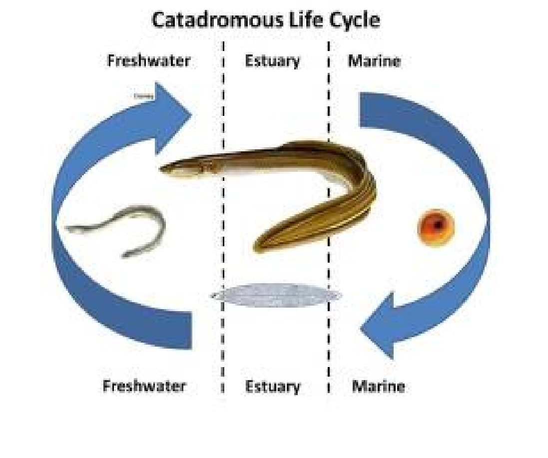
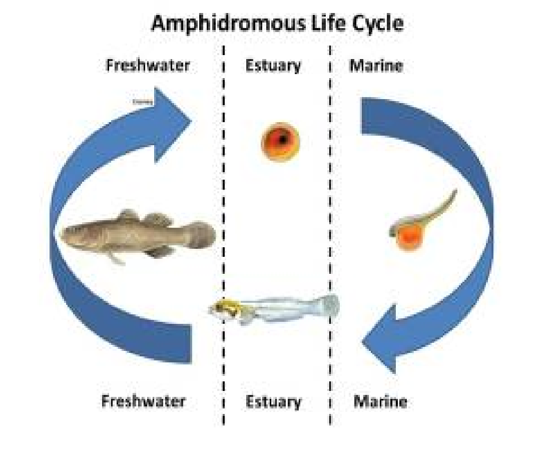
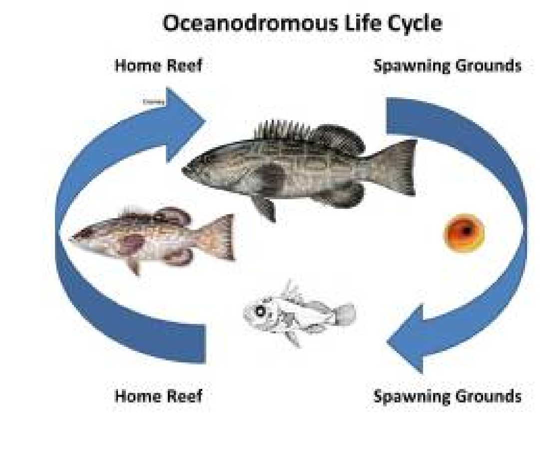
	
Stolephorus commersonnii Lacepède, 1803	*Lates calcarifer* Bloch, 1790
	
Himantura bleekeri (Blyth, 1860) *Trichiurus lepturus* Linnaeus, 1758 *Pampus chinensis* (Euphrasen, 1788) *Parastromateus niger* (Bloch, 1795) *Muraenesox talabonoides* (Bleeker, 1853)	*Lutjanus argentimaculatus* (Forsskål, 1775) *Johnius dussumieri* (Cuvier, 1830) *Tachysurus thalassinus* (Rüppell, 1837) *Rastrelliger kanagurta* (Cuvier, 1816) *Scomberomorus commerson* Lacepède 1800 *S. guttatus* Fowler, 1905 *Katsuwonus pelamis* (Linnaeus, 1758) *Thunnus albacores* (Bonnaterre, 1788) *Coryphaena hippurus* Linnaeus, 1758 *Makaira indica* (Cuvier, 1832) *Xiphias gladius* Linnaeus, 1758 *Pampus argenteus* (Euphrasen, 1788) *Sepia pharaonis* Ehrenberg, 1831

Figure 1: Migration types of marine fish and molluscan species.

Gears used for capturing common edible marine species landing/sold at Fishing Harbor and local fish markets of Visakhapatnam

Gears used for capturing marine species sold locally were recorded using the terminology followed in the International Standard Statistical Classification of Fishing Gear (ISSCFG, 2016). Information on gear types used was collected from fishermen who were involved in fish harvesting and this information was presented species-wise. Further, whether the gear-types change according to the season for capturing the same species was also collected. The period of occurrence, depth of occurrence (in meters), size at maturity and spawning season were also recorded for each captured species.

Description of morphometrics of common edible marine species landing/sold at Fishing Harbor and local fish markets of Visakhapatnam

Morphometric data was collected for all marine species sold locally. The standard length, total length, body depth, head length and weight were recorded for teleost species. Disc length, total length, and weight were recorded for the elasmobranch species. Mantle length, total length, and weight were recorded for the molluscan species. Length and depth measurements were recorded in centimeters while weight was recorded in grams. For all measurements, ten specimens were used for each species. The range, average, and standard deviation values were recorded for each species.

Physico-chemical characteristics of coastal water of Visakhapatnam

Ten samples of coastal surface water collected on different days in the month of May 2019 at 500 m away from Visakhapatnam harbor were analyzed for pH, salinity, dissolved oxygen, and biological oxygen demand. pH was measured by a standardized pH meter. Dissolved oxygen (DO) and Biological Oxygen Demand (BOD) were determined using the Azide modification of the Winkler Method. Salinity was recorded using Salinity meter. Temperature was recorded with a precision thermometer. Based on the values recorded from all ten samples of surface sea water, range, mean, and standard deviation have been calculated.

Morphological characteristics of Pomfret species

Morphological characteristics of three Promfret fish species *Pampus argenteus, Pampus chinensis* and *Parastromateus niger* were described because they were selected for the assessment of protein content muscle portion and heavy metals arsenic, cadmium, mercury, and lead in muscle and gill parts. The morphological characters described enable to distinguish these three species from each other and also to identify easily in sea water and at selling point.

Determination of total protein content in the muscle tissue of *Pampus argenteus, Pampus chinensis* and *Parastromateus niger*

Ten fresh samples from ten different individuals of each fish species were collected from fishing harbor at Visakhapatnam. They were kept in cold iced box, taken to the laboratory and kept in a freezer before it was used for the determination of total protein content. The total protein content was determined by estimating the total nitrogen using Indian Standard Method (IS 7219-1973). In this method, the sample consisting of organic nitrogen was oxidized with concentrated sulphuric acid to convert it into ammonium sulphate in a micro Kjeldahl flask. Mercury was added to digestion mixture as a catalyst. The digest was diluted, made alkaline with anhydrous sodium sulphate and then distilled. Ammonia was liberated by adding an excess of alkali and was quantitatively distilled into a measured volume of standard sulphuric acid and total nitrogen was determined titrimetrically. The percent of protein content in the sample was calculated. This work was done at Vimta Labs Ltd., Visakhapatnam.

Assessment of heavy metals in the muscle tissue and gill portions of *Pampus argenteus, Pampus chinensis and Parastromateus niger*

In digestion vessel, 0.5g of homogenized muscle/gill samples were taken. Then, eight ml of concentrated nitric acid, one ml of concentrated hydrochloric acid and one ml of hydrogen peroxide were added to the homogenized samples. The digestion vessel was closed and then transferred to microwave digestion system at 190°C for 45 minutes. After completion of the digestion, digestion vessels were removed from the system, and cooled to room temperature, the sample was made up to 25 ml with distilled water. The concentrations of heavy metals, arsenic, cadmium, mercury, and lead were determined using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) instrument.

Comparison of heavy metal concentrations analyzed in muscle and gill portions of Pomfret fish species with the permissible standards set out by different organizations

The detected heavy metal concentrations of arsenic, cadmium, mercury, and lead in muscle and gill portions of all the three Pomfret fish species were compared with the recommended limits permitted by European Union Regulations (EU) 2006, Food and Agriculture Organization (FAO)/World Health Organization (WHO) 2011, Ministry of Agriculture, Fisheries and Food (MAFF) and Food Safety and Standards Authority of India (FSSAI) as available.

RESULTS

Marine fin and shell fish species of coastline of Andhra Pradesh

An inventory of marine fish species of coastline of Andhra Pradesh included fin and shell fish species. Together, a total of 212 species have been integrated into this inventory (Tab. 1). Fin fishes include bony fishes while shellfishes include crustaceans and molluscs. Fin fishes included Elasmobranchs which are characteristically cartilaginous and Teleosts which are characteristically bony. Elasmobranchs were represented by 26 species consisting of sharks, skates, and rays. Sharks included 12 species belonging to five families. They were *Chiloscyllium indicum* (Hemiscyllidae), *Rhincodon typus* (Rhincodontidae), *Stegostoma fasciatum* (Stegostomatidae), *Carcharhinus melanopterus, C. dussumieri, C. sorrah, Galeocerdo cuvieri*, *Rhizoprionodon acutus*, *Scoliodon laticaudus* (Carcharhinidae), *Eusphyra blochii*, *Sphyrna mokarran*, and *S. zygaena* (Sphyrnidae). Skates included five species belonging to three families. They were *Rhina ancylostoma, Rhynchobatus djiddensis* (Rhinidae), *Rhinobatus granulatus* (Rhinobatidae), *Anoxypristis cuspidate*, and *Pristis microdon* (Pristidae). Rays were represented by nine species belonging to four families. They were *Dasyatis zugei*, *Himantura bleekeri, H. uarnak* (Dasyatidae), *Aetomylaeus maculatus* (Myliobatidae), *Manta birostsis, Mobula diabolus* (Mobulidae), *Benthobatis moresbyi, Narcine brunnea,* and *Narcine timlei* (Narcinidae).

Table 1: Inventory of marine fin and shell fish species of coastline of Andhra Pradesh.

S. No.	Family	Scientific name	Groups	Common name	Local/ Telugu name
Fin fishes					
Elasmobranchs					
1.	Hemiscylliidae	*Chiloscyllium indicum* (Gmelin, 1789)	Sharks	Ridge black cat shark	Bokkisorrah
2.	Rhincodontidae	*Rhincodon typus* (Smith, 1828)		Whale shark	Pulibokku sorrah
3.	Stegostomatidae	*Stegostoma fasciatum* (Hermann, 1783)		Zebra shark	Charala sorrah
4.	Carcharhinidae	*Carcharhinus melanopterus* (Quoy and Gaimard, 1824)		Black tip reef shark	Nallarekkala sorrah
5.	Carcharhinidae	*Carcharhinus dussumieri* (Muller and Henle, 1839)		White cheeked shark	Siga sorrah
6.	Carcharhinidae	*Carcharhinus sorrah* (Muller and Henle, 1839)		Sorrah	Pala sorrah
7.	Carcharhinidae	*Galeocerdo cuvieri* (Peron and Lesueur, 1822)		Tiger shark	Puli sorrah
8.	Carcharhinidae	*Rhizoprionodon acutus* (Ruppell, 1837)		Grey dog shark/Milk shark	Kukka sorrah
9.	Carcharhinidae	*Scoliodon laticaudus* (Muller and Henle, 1838)		Yellow dog shark	Pasupu kukka sorrah
10.	Sphyrnidae	*Eusphyra blochii* (Cuvier, 1816)		Arrow headed hammer head shark	Kommu sorrah
11.	Sphyrnidae	*Sphyrna mokarran* (Ruppell, 1837)		Squat-headed Hammer head shark	Kommu sorrah
12.	Sphyrnidae	*Sphyrna zygaena* (Linnaeus, 1758)		Round headed Hammer headed shark	Kommu sorrah
13.	Rhinidae	*Rhina ancylostoma* (Bloch and Schneider, 1801)	Skates	Bow mouthed angel fish	Tiragalidi-mma
14.	Rhinidae	*Rhynchobatus djiddensis* (Forsskal, 1775)		White spotted shovel nose ray	Ulava
15.	Rhinobatidae	*Rhinobatus granulatus* (Cuvier, 1829)		Granulated shovel nose ray	Adalam
16.	Pristidae	*Anoxypristis cuspidata* (Latham, 1794)		Pointed saw fish	Rampapu sorrah
17.	Pristidae	*Pristis microdon* (Latham, 1794)		Small toothed saw fish	Chinnara-mpapu sorrah

Table 1 (continued): Inventory of marine fin and shell fish species of coastline of Andhra Pradesh.

S. No.	Family	Scientific name	Groups	Common name	Local/ Telugu name
Fin fishes					
Elasmobranchs					
18.	Dasyatidae	*Dasyatis zugei* (Muller and Henle, 1841)	Rays	Pale edge sting ray	Teku chepa
19.	Dasyatidae	*Himantura bleekeri* (Blyth, 1860)	Rays	Whiptail sting ray	Mullu teku
20.	Dasyatidae	*Himantura uarnak* (Gmelin, 1789)	Rays	Banded whip tail sting ray/Honey combed sting ray	Katlamu-llu teku
21.	Myliobatidae	*Aetomylaeus maculatus* (Gray, 1834)	Rays	Mottled eagle ray	Greddamu-kku teku
22.	Mobulidae	*Manta birostris* (Walbaum, 1792)	Rays	Giant Manta/Devil ray	Deyyapu teku
23.	Mobulidae	*Mobula diabolus* (Shaw, 1804)	Rays	Lesser devil ray	Chinna deyyapu teku
24.	Narcinidae	*Benthobatis moresbyi* (Alcock, 1898)	Rays	Electric ray	Jalluthimiri teku
25.	Narcinidae	*Narcine brunnea* (Annandale, 1909)	Rays	Brown electric ray	Thimiri teku
26.	Narcinidae	*Narcine timlei* (Bloch and Schneider, 1801)	Rays	Black Spotted electric ray	Chukkala thimri teku
Teleosts					
27.	Elopidae	*Elops machnata* (Forsskal, 1775)	Ten Pounders	Ten pounder	Jalugu
28.	Megalopidae	*Megalops cyprinoides* (Broussonet, 1782)	Tarpons	Indo-pacific tarpon	Kanninga

Table 1 (continued): Inventory of marine fin and shell fish species of coastline of Andhra Pradesh.

S. No.	Family	Scientific name	Groups	Common name	Local/ Telugu name
Fin fishes					
Teleosts					
29.	Clupeidae	*Anodontostoma chacunda* (Hamilton, 1822)	Shads and Sardines	Chancunda gizzard shad	Madurulu
30.	Clupeidae	*Dussumieria elopsoides* (Bleeker, 1849)		Rainbow sardine	Morava
31.	Clupeidae	*Dussumieria acuta* (Valenciennes, 1847)		Rainbow sardine	Morava
32.	Clupeidae	*Escualosa thoracata* (Valenciennes, 1847)		White sardine	Tella kavvallu
33.	Clupeidae	*Hilsa ilisha* (Hamilton, 1822)		Indian shad	Polasa
34.	Clupeidae	*Hilsa kelee* (Cuvier, 1829)		Five spot herring	Keelailu
35.	Clupeidae	*Hilsa toli* (Valenciennes, 1847)		Chinese herring	Katumeenu/ Elasa
36.	Clupeidae	*Nematalosa nasus* (Bloch, 1795)		Blochs gizzard chad	Komu
37.	Clupeidae	*Opisthopterus tardoore* (Cuvier, 1829)		Tardoore	Akuchepa
38.	Clupeidae	*Sardinella fimbriata* (Valenciennes, 1847)		Fringe scale sardine	Ballakavvu-llu
39.	Clupeidae	*Sardinella gibbosa* (Bleeker, 1849)		Gold stripped sardine	Soodimooti kavvallu
40.	Clupeidae	*Sardinella longiceps* (Valenciennes, 1847)		Indian oil sardine	Noonikavva-llu
41.	Pristigasteridae	*Ilisha elongata* (Bennett, 1830)		Elongate ilisha	Sana engallu
42.	Pristigasteridae	*Ilisha megaloptera* (Swainson, 1839)		Big eye ilisha	Kallaengallu
43.	Pristigasteridae	*Ilisha melastoma* (Bloch and Schneider, 1801)		Indian ilisha	Engallu
44.	Pristigasteridae	*Pellona ditchela* (Valenciennes 1847)		Indian pellona	Guddi engallu
45.	Pristigasteridae	*Raconda russeliana* (Gray, 1831)		Russell’s smooth back herring	Olikithatti

Table 1 (continued): Inventory of marine fin and shell fish species of coastline of Andhra Pradesh.

S. No.	Family	Scientific name	Groups	Common name	Local/ Telugu name
Fin fishes					
Teleosts					
46.	Engraulidae	*Coilia dussumieri* (Valenciennes, 1848)	Anchovies	Gold spotted grenadier anchovy	Mangalakathi
47.	Engraulidae	*Setipinna taty* (Valenciennes, 1848)		Hair fin anchovy	Thokapariga
48.	Engraulidae	*Stolephorus bataviensis* (Hardenberg, 1933)		Batavian anchovy	Nethallu
49.	Engraulidae	*Stolephorus commersonnii* (Lacepede, 1803)		Commerson's anchovy	Nethallu
50.	Engraulidae	*Stolephorus devisi* (Whitley, 1940)		Devisi anchovy	Namalan-ethallu
51.	Engraulidae	*Stolephorus indicus* (Van Hasselt, 1823)		Indian anchovy	Nethallu
52.	Engraulidae	*Thryssa dussumieri* (Valenciennes, 1848)		Dussumier's anchovy	Pottiporava
53.	Engraulidae	*Thryssa mystax* (Bloch and Schneider, 1801)		Moustached anchovy	Palliporava/ Nedumpo-rava
54.	Engraulidae	*Thryssa setirostris* (Broussonet, 1782)		Long jaw anchovy	Geddampo-rava/ Yeekaporava
55.	Chirocentridae	*Chirocentrus dorab* (Forsskal, 1775)	Wolf Herrings	Dorab wolf herring	Mullivala
56.	Chirocentridae	*Chirocentrus nudus* (Swainson, 1839)		White fin wolf herring	Vala
57.	Chanidae	*Chanos chanos* (Forsskal, 1775)	Milk Fishes	Milk fish	Palachepa/ Palabonta

Table 1 (continued): Inventory of marine fin and shell fish species of coastline of Andhra Pradesh.

S. No.	Family	Scientific name	Groups	Common name	Local/ Telugu name
Fin fishes					
Teleosts					
58.	Synodontidae	*Saurida gracilis* (Quoy and Gaimard, 1824)	Lizard Fishes	Slender lizard fish	Sannabade-metta
59.	Synodontidae	*Saurida tumbil* (Bloch, 1795)		Greater lizard fish	Pedda bademetta
60.	Synodontidae	*Saurida undosquamis* (Richardson, 1848)		Brush tooth lizard fish	Bademetta
61.	Synodontidae	*Trachinocephalus myops* (Forster, 1801)		Blunt nose lizard fish	Esakadondu-lu
62.	Synodontidae	*Harpadon nehereus* (Hamilton, 1822)	Bombay duck	Bombay duck	Vanamatta/ Kukkamatta
63.	Ariidae	*Tachysurus dussumieri* (Valenciennes, 1840)	Cat fishes	Dussumier's cat fish	Penkijella
64.	Ariidae	*Tachysurus tenuispinis* (Day, 1877)		Thin spined cat fish	Nallajella
65.	Ariidae	*Tachysurus thalassinus* (Ruppell, 1837)		Giant cat fish	Tella jella
66.	Bagridae	*Macrones gulio* (Hamilton, 1822)		Long whiskers cat fish	Jellakoyyallu
67.	Plotosidae	*Plotosus anguillaris* (Bloch, 1794)	Cat fish	Stripped cat fish	Silthi
68.	Plotosidae	*Plotosus canius* (Hamilton, 1822)		Canine cat fish	Engilai
69.	Anguillidae	*Anguilla bicolor bicolor* (McClelland, 1844)	Eels and Congers	Level finned	Nalla pamu
70.	Anguillidae	*Anguilla nebulosa n.* (McClelland, 1844)		Long finned eel	Nalla pamu
71.	Muraenesocidae	*Muraenesox talabonoides* (Bleeker, 1853)		Indian pike conger	Tella pamu
72.	Muraenesocidae	*Muraenesox cinereus* (Forsskal, 1775)		Dagger toothed pike conger	Pasupu pamu

Table 1: Inventory of marine fin and shell fish species of coastline of Andhra Pradesh.

S. No.	Family	Scientific name	Groups	Common name	Local/ Telugu name
Fin fishes					
Teleosts					
73.	Belonidae	*Strongylura crocodilus* (Peron and Lesueur, 1821)	Full beaks (Gar fishes)	Fork tail aligator gar	Kadurulu
74.	Hemiramphidae	*Hemirhamphus marginatus* (Forsskal, 1775)	Half beaks	Barred half beak	Kadurulu
75.	Exocoetidae	*Cypselurus cyanopterus* (Valenciennes, 1847)	Flying fishes	Blue spot flying fish	Gopirangulu
76.	Exocoetidae	*Exocoetus volitans* (Linnaeus, 1758)		Two winged flying fish	Thooreegalu
77.	Fistulariidae	*Fistularia petimba* (Lacepede, 1803)	Flute mouths	Smooth flute mouth	Kolasi
78.	Fistulariidae	*Fistularia villosa* (Klunzinger, 1871)		Rough flute mouth	Garukukolasi
79.	Sphyraenidae	*Sphyraena jello* (Cuvier, 1829)	Barracudas	Banned barracuda	Charala seelapotu
80.	Sphyraenidae	*Sphyraena obtusata* (Cuvier, 1829)		Obtuse barracuda	Seelapotu
81.	Mugilidae	*Liza tade* (Forsskal, 1775)	Mullets	Tade grey mullet	Kaniselu
82.	Mugilidae	*Mugil cephalus* (Linnaeus, 1758)		Flat head grey mullet	Kattachepa/ Bontalu
83.	Mugilidae	*Valamugil cunnesius* (Valenciennes, 1836)		Long fin grey mullet	Kaniselu

Table 1 (continued): Inventory of marine fin and shell fish species of coastline of Andhra Pradesh.

S. No.	Family	Scientific name	Groups	Common name	Local/ Telugu name
Fin fishes					
Teleosts					
84.	Polynemidae	*Eleutheronema tetradactylum* (Shaw, 1804)	Thread fins	Four finger thread fin	Budathamaga
85.	Polynemidae	*Polynemus indicus* (Shaw, 1804)		Indian thread fin	Magachepa
86.	Polynemidae	*Polynemus sexfilis* (Valenciennes, 1831)		Golden six threadfin	Maga
87.	Polynemidae	*Polynemus sextarius* (Bloch and Schneider, 1801)		Black spot thread fin	Nallama chamaga
88.	Latidae	*Lates calcarifer* (Bloch, 1790)	Sea perches Reef cods	Giant sea perch/Sea bass	Pandugoppa/ Pandumoyya
89.	Serranidae	*Epinephelus areolatus* (Forsskal, 1775)		Aerolated reef cod	Ratibonta
90.	Serranidae	*Epinephelus diacanthus* (Valenciennes, 1828)		Six barred reef cod	Ratibonta
91.	Serranidae	*Epinephelus tauvina* (Forsskal, 1775)		Greasy reef cod	Ratibonta
92.	Terapontidae	*Terapon jarbua* (Forsskal, 1775)	Tiger Perches	Crescent tiger perch	Keelupotu
93.	Terapontidae	*Terapon theraps* (Cuvier, 1829)		Large scaled tiger perch	Keelupotu
94.	Priacanthidae	*Priacanthus cruentatus* (Lacepede, 1801)	Bulls eyes	Blood colored bulls eye	Errabochelu/ Yerrichepalu
95.	Priacanthidae	*Priacanthus hamrur* (Forsskal, 1775)		Dusky finned bulls eye	Bochelu/ Yerrichepalu
96.	Sillaginidae	*Sillago sihama* (Forsskal, 1775)	Whitings	Silver whiting	Surangi
97.	Sillaginidae	*Sillago maculata* (Quoy and Gaimard, 1824)	Whitings	Trumpetter whiting	Surangi

Table 1 (continued): Inventory of marine fin and shell fish species of coastline of Andhra Pradesh.

S. No.	Family	Scientific name	Groups	Common name	Local/ Telugu name
Fin fishes					
Teleosts					
98.	Lactariidae	*Lactarius lactarius* (Bloch and Schneider, 1801)	White fishes	White fish	Sudumulu
99.	Rachycentridae	*Rachycentron canadus* (Linnaeus, 1766)	Cobias	Cobia	Peddamatta/ Nallamatta
100.	Carangidae	*Alectis indicus* (Ruppell, 1830)	Carangids	Indian thread fin trevally	Thokalapara/ Gurrampara
101.	Carangidae	*Alepes djedaba* (Forsskal, 1775)		Djeddaba trevally	Kallodugu
102.	Carangidae	*Carangoides malabaricus* (Bloch and Schneider, 1801)		Malabar trevally	Thalampara
103.	Carangidae	*Caranx ignobilis* (Forsskal, 1775)		Yellow fin trevally	Pasupupara
104.	Carangidae	*Decapterus russelli* (Ruppell, 1830)		Russelli's scad	Pilliodugu
105.	Carangidae	*Decapterus dayi* (Wakiya, 1924)		Day's scad	Pilliodugu
106.	Carangidae	*Megalaspis cordyla* (Linnaeus, 1758)		Hard tail scad	Bokkodugu
107.	Carangidae	*Scomberoides commersonnianus* (Lacepede, 1801)		Talang queen fish	Tolupara
108.	Carangidae	*Scomberoides lysan* (Forsskal 1775)		Talang leather skin	Pasuputolu-para
109.	Carangidae	*Scomberoides tala* (Forsskal, 1775)		Deep queen fish	Kamsalitolu para
110.	Carangidae	*Scomberoides tol* (Cuvier, 1832)		Slender queen fish	Sannatolu-para
111.	Carangidae	*Trachinotus blochii* (Laceped, 1801)		Snub nose pompano	Chanduvapa-ra

Table 1 (continued): Inventory of marine fin and shell fish species of coastline of Andhra Pradesh.

S. No.	Family	Scientific name	Groups	Common name	Local/ Telugu name
Fin fishes					
Teleosts					
112.	Menidae	*Mene maculata* (Bloch and Schneider, 1801)	Moon fishes	Moon fish	Chukkala chanduva
113.	Coryphaenidae	*Coryphaena hippurus* (Linnaeus, 1758)	Dolphin fishes	Common dolphin fish/Mahi Mahi	Avalosu
114.	Lutjanidae	*Lutjanus argentimaculatus* (Forsskal, 1775)	Snappers	Mangrove red snapper	Ratigoraka/ Yerragoraka
115.	Lutjanidae	*Lutjanus johnii* (Bloch, 1792)		Johns snapper	Samarlu/ Yerragoraka
116.	Nemipteridae	*Nemipterus delagoae* (Smith, 1941)	Thread fin breams	Delagoan threadfin bream	Yerra gulivindalu/ Gulivindalu
117.	Nemipteridae	*Nemipterus japonicus* (Bloch, 1791)		Japanese thread fin bream	Yerra gulivinda/ Bandi gulivindalu
118.	Nemipteridae	*Nemipterus mesoprion* (Bleeker, 1853)		Red filament thread fin bream	Yerra gulivindalu/ Bandiguli-vindalu
119.	Lobotidae	*Lobotes surinamensis* (Bloch, 1790)	Triple tails	Brown triple tail	Maata

Table 1: Inventory of marine fin and shell fish species of coastline of Andhra Pradesh.

S. No.	Family	Scientific name	Groups	Common name	Local/ Telugu name
Fin fishes					
Teleosts					
120.	Leiognathidae	*Gazza minuta* (Bloch, 1795)	Silver bellies (Pony fishes)	Toothed pony fish	Sudumu kara
121.	Leiognathidae	*Leiognathus bindus* (Valenciennes, 1835)		Orange fin pony fish	Bendu kara
122.	Leiognathidae	*Leiognathus dussumieri* (Valenciennes, 1835)		Dussumier's pony fish	Charala kara
123.	Leiognathidae	*Leiognathus equulus* (Forsskal, 1775)		Common pony fish	Chanduva kara
124.	Leiognathidae	*Leiognathus splendens* (Cuvier 1829)		Splendid pony fish	Tatta kara
125.	Leiognathidae	*Secutor insidiator* (Bloch, 1787)		Pugnose pony fish	Chukka kara
126.	Leiognathidae	*Secutor ruconius* (Hamilton, 1822)		Deep pug nose pony fish	Chinni chukka kara
127.	Gerreidae	*Gerres filamentosus* (Cuvier, 1829)	Mojarras	Whip fin mojarra	Jaggari/Vada-gava
128.	Gerreidae	*Pentaprion longimanus* (Cantor, 1849)		Long fin mojarra	Karnigavala/ Varipindikudelu
129.	Haemulidae	*Pomadasys hasta* (Bloch, 1790)	Grunters	Lined silver grunt	Pandugoraka
130.	Haemulidae	*Pomadasys maculatus* (Bloch 1793)		Blotched grunt	Karipi
131.	Sciaenidae	*Atrobucca nibe* (Jordan and Thompson, 1911)	Croakers	Black mouthed croaker	Karrimooti gorasa
132.	Sciaenidae	*Johnieops vogleri* (Bleeker, 1853)		Drab croaker	Gorasa
133.	Sciaenidae	*Johnius carutta* (Bloch, 1793)		Karut croaker	Nalla gorasa/ Charagorassa
134.	Sciaenidae	*Johnius dussumieri* (Cuvier, 1830)		Bearded croaker	Geddam gorassa
135.	Sciaenidae	*Kathala axillaris* (Cuvier, 1830)		Kathala croaker	Palli gorassa
136.	Sciaenidae	*Nibea maculata* (Bloch and Schneider, 1801)		Blotches croaker	Nallamachala gorassa
137.	Sciaenidae	*Otolithes ruber* (Bloch and Schneider, 1801)		Tiger toothed croaker	Villigorassa/ Palla gorassa
138.	Sciaenidae	*Pennahia macrophthalmus* (Bleeker, 1849)		Big eye croaker	Kalla gorassa
139.	Sciaenidae	*Protonibea diacanthus* (Lacepede, 1802)		Spotted croaker	Pandu gorassa

Table 1 (continued): Inventory of marine fin and shell fish species of coastline of Andhra Pradesh.

S. No.	Family	Scientific name	Groups	Common name	Local/ Telugu name
Fin fishes					
Teleosts					
140.	Mullidae	*Upeneus sulphureus* (Cuvier, 1829)	Goat fishes	Yellow goat fish	Pasupu gullivinda
141.	Mullidae	*Upeneus sundaicus* (Bleeker, 1855)		Sunda goat fish	Gulivinda
142.	Mullidae	*Upeneus vittatus* (Forsskal, 1775)		Yellow stripped goat fish	Chara gulivinda
143.	Drepaneidae	*Drepane punctata* (Linnaeus, 1758)	Sickle fish	Spotted sickle fish	Tatti/Tha-rlam
144.	Scatophagidae	*Scatophagus argus* (Linnaeus, 1766)	Butter fishes	Spotted butter fish	Eetithippa
145.	Trichiuridae	*Trichiurus lepturus* (Linnaeus, 1758)	Ribbon fishes	Large head hair tail	Pattisavada
146.	Trichiuridae	*Trichiurus russelli* (Dutt and Thankam, 1967)		Small head hair tail	Savada
147.	Trichiuridae	*Lepturacanthus savala* (Cuvier, 1829)		Small head hair tail	Savallu
148.	Scombridae	*Auxis thazard* (Lacepede, 1800)	Tunas	Frigate tuna	Tikka soora
150.	Scombridae	*Euthynnus affinis* (Cantor, 1849)		Little tuna	Mayapu soora
151.	Scombridae	*Katsuwonus pelamis* (Linnaeus, 1758)		Skipjack tuna	Namala soora
152.	Scombridae	*Thunnus albacares* (Bonnaterre, 1788)		Yellowfin tuna	Recca soora
153.	Scombridae	*Rastrelliger faughni* (Matsui, 1967)	Mackerels	Faughni Mackerel	Kanagadatha
154.	Scombridae	*Rastrelliger kanagurta* (Cuvier, 1816)		Indian mackerel	Kanagadatha

Table 1 (continued): Inventory of marine fin and shell fish species of coastline of Andhra Pradesh.

S. No.	Family	Scientific name	Groups	Common name	Local/ Telugu name
Fin fishes					
Teleosts					
155.	Scombridae	*Scomberomorus commerson* (Lacepede, 1800)	Seer fishes	Narrow barred seer fish/King fish	Konemu
156.	Scombridae	*Scomberomorus guttatus* (Bloch and Schneider, 1801)		Indo pacific seer fish	Vanjaramu
157.	Scombridae	*Scomberomorus koreanus* (Kishinouye, 1915)		Korean seer fish	Ballavanja-ramu
158.	Scombridae	*Scomberomorus lineolatus* (Cuvier 1831)		Streaked seer fish	Magarasi
159.	Istiophoridae	*Istiophorus platypterus* (Shaw, 1792)	Sail fishes (Marlin)	Sail fish	Nemalipuri konemu
160.	Istiophoridae	*Makaira indica* (Cuvier, 1832)		Black marlin	Nalla kommu konemu
161.	Xiphiidae	*Xiphias gladius* (Linnaeus, 1758)	Sword fish	Sword fish	Kommu konemu
162.	Stromateidae	*Pampus argenteus* (Euphrasen, 1788)	Pomfrets	Silver Pomfret	Tella chanduva
163.	Stromateidae	*Pampus chinensis* (Euphrasen, 1788)		Chinese Pomfret	Attukoyya/ Atukula chanduva
164.	Carangidae	*Parastromateus niger* (Bloch, 1795)		Black Pomfret	Nalla chanduva
165.	Nomeidae	*Psenes indicus* (Day, 1871)	Drift fishes	Indian drift fish	Methapara/ Chalaneeti chepa
166.	Kurtidae	*Kurtus indicus* (Bloch, 1786)	Hump heads	Indian hump head	Poosa pariga

Table 1 (continued): Inventory of marine fin and shell fish species of coastline of Andhra Pradesh.

S. No.	Family	Scientific name	Groups	Common name	Local/ Telugu name
Fin fishes					
Teleosts					
167.	Oxudercidae	*Trypauchen vagina* (Bloch and Schneider, 1801)	Gobies	Burrowing goby	Dondulu
168.	Platycephalidae	*Platycephalus indicus* (Linnaeus, 1758)	Flat Heads	Indian flat head	Sotlamari
169.	Psettodidae	*Psettodes erumei* (Bloch and Schneider, 1801)	Flat fishes	Indian halibut	Eddunalika
170.	Paralichthyidae	*Pseudorhombus arsius* (Hamilton, 1822)		Large toothed flounder	Nammina-lika/ Bepinalika
171.	Cynoglossidae	*Cynoglossus macrolepidotus* (Bleeker, 1851)		Large scaled tongue sole	Tambaratta
172.	Echeneidae	*Echeneis naucrates* (Linnaeus, 1758)		Slender sucker fish	Untuchepa

Table 1 (continued): Inventory of marine fin and shell fish species of coastline of Andhra Pradesh.

S. No.	Family	Scientific name	Groups	Common name	Local/ Telugu name
Shell fishes					
Crustaceans					
173.	Solenoceridae	*Solenocera crassicornis* (Milne Edwards, 1837)	Penaeids (Prawns)	Coastal mud prawn	Kukkaroyya
174.	Solenoceridae	*Solenocera hextii* (Alcock, 1891)		Deep sea mud shrimp	Yerra royya
175.	Penaeidae	*Metapenaeus affinis* (Milne Edwards, 1837)		Jinga prawn	Gullaroyya/ Keliroyya
176.	Penaeidae	*Metapenaeus brevicornis* (Milne Edwards, 1837)		Yellow prawn	Pasupu royya/ Puvvalin
177.	Penaeidae	*Metapenaeus dobsoni* (Miers, 1878)		Flower tail prawn	Chinkiroyya
178.	Penaeidae	*Metapenaeus monoceros* (Fabricius, 1798)		Speckled prawn	Chakuroyya/ Kalandhan
179.	Penaeidae	*Parapenaeopsis hardwickii* (Miers, 1878)		Spear prawn	Gulla royya
180.	Penaeidae	*Parapenaeopsis acclivirostris* (Alcock, 1905)		Hawk nose prawn	Gulla royya
181.	Penaeidae	*Parapenaeopsis sculptilis* (Heller, 1862)		Rainbow prawn	Gulla royya
182.	Penaeidae	*Parapenaeopsis stylifera* (Milne Edwards 1837)		Kiddi prawn	Gulla royya/ Karrkkadi
183.	Penaeidae	*Penaeus indicus* (Milne Edwards, 1837)		Indian white prawn	Tella royya/ Narram
184.	Penaeidae	*Penaeus japonicus* (Spence Bate, 1888)		Kuruma prawn	Kallirorra
185.	Penaeidae	*Penaeus merguiensis* (De Mann, 1888)		Banana prawn	Kallirorra
186.	Penaeidae	*Penaeus monodon* (Fabricius, 1798)		Giant tiger prawn	Katla royya
187.	Penaeidae	*Penaeus semisulcatus* (De Hann, 1844)		Green tiger prawn	Noone royya
188.	Penaeidae	*Trachypenaeus curvirostris* (Stimpson, 1860)		Rough shrimp	Garu royya
189.	Pandalidae	*Pandalus borealis* (Kroyer, 1838)		Northern shrimp	Pink royya

Table 1 (continued): Inventory of marine fin and shell fish species of coastline of Andhra Pradesh.

S. No.	Family	Scientific name	Groups	Common name	Local/ Telugu name
Shell fishes					
Crustaceans					
190.	Sergestidae	*Acetes indicus* (Milne Edwards, 1830)	Non-penaeid Prawns	Paste shrimp	Kooni royya/ Royya pottu
191.	Palaemonidae	*Macrobrachium malcolmsonii* (Milne-Edwards, 1844)		Monsoon River prawn	Neekkantapu royya
192.	Palaemonidae	*Macrobrachium rosenbergii* (De Man, 1879)		Giant River prawn	Peddaneela-kantapu royya
193.	Palaemonidae	*Nematopalaemon tenuipes* (Henderson, 1893)		Spider prawn	Chingudu royya
194.	Lysmatidae	*Exhippolysmata ensirostris* (Kemp, 1914)		Hunter shrimp	Bonuguroyya
195.	Palinuridae	*Panulirus homarus* (Linnaeus, 1758)	Lobsters	Green spiny lobster	Ratiroyya
196.	Palinuridae	*Panulirus polyphagus* (Herbst, 1793)		Banded spiny lobster/Mud spiny lobster	Katlarati royya
197.	Scyllaridae	*Thenus orientalis* (Lund, 1793)		Mud lobster	Tapatapalu/ Madataroyya
198.	Portunidae	*Scylla serrata* (Null, 2001)	Crabs	Green mud crab	Mandapeeta
199.	Portunidae	*Portunus sanguinolentus* (Herbst, 1783)		Spotted crab	Chukkala-petta
200.	Portunidae	*Portunus pelagicus* (Linnaeus, 1758)		Reticulate crab	Gelaipeeta
201.	Portunidae	*Charybdis cruciata* (Herbst, 1794)		Cross crab	Yerripeeta
202.	Squillidae	*Oratosquilla nepa* (Latreille, 1828)	Stomatopods	Mantis shrimp	Teluroyya

Table 1: Inventory of marine fin and shell fish species of coastline of Andhra Pradesh.

S. No.	Family	Scientific name	Groups	Common name	Local/ Telugu name
Molluscs					
203.	Arcidae	*Anadara granosa* (Linnaeus, 1758)	Bivalves	Cockle (Blood clam)	Buditigulla
204.	Mytilidae	*Perna indica* (Kuriakose and Nair, 1976)		Brown mussel	Alagulla
205.	Mytilidae	*Perna viridis* (Linnaeus, 1758)		Green mussel	Alachippa
206.	Placunidae	*Placuna placenta* (Linnaeus, 1758)		Window Pane oyster	Talapugolla
207.	Ostreidae	*Crassostrea madrasensis* (Preston, 1916)		East coast edible oyster	Dippa kannu
208.	Veneridae	*Meretrix meretrix* (Linnaeus, 1758)		Clam	Boodidhi-gulla
209.	Sepiidae	*Sepia aculeata* (Van Hasselt, 1835)	Cephalopods	Cuttle fish	Buddakalvinda/ Komitichanchulu
210.	Sepiidae	*Sepia pharaonis* (Ehrenberg, 1831)		Cuttle fish	Charala kalvinda
211.	Sepiidae	*Sepiella inermis* (Van Hasselt 1835)		Cuttle fish	Buddakalvinda/ Komitichanchulu
212.	Loliginidae	*Loligo duvaucelii* (d'Orbigny, 1835)		Squid	Kandavaya/ Kolakalivinda

Teleosts were represented by 146 species consisting of Ten Pounders, Tarpons, Shads, Sardines, Anchovies, Wolf Herrings, Milk Fishes, Lizard Fishes, Bombay Ducks, Cat fishes, Cat fish eels, Eels and Congers, Full beaks (Gar fishes), Half beaks, Flying fishes, Flute mouths, Barracudas, Mullets, Thread fins, Sea perches, Reef cods, Tiger Perches, Bulls eye, Whitings, White fishes, Cobias, Carangids, Moon fishes, Dolphin fishes, Snappers, Thread fin breams, Triple tails, Silver bellies (Pony fishes), Mojarras, Grunters, Croakers, Goat fishes, Sickle fishes, Butter fishes, Ribbon fishes, Tunas, Mackerels, Seer fishes, Sail fishes, Sword fishes, Pomfrets, Drift fishes, Hump heads, Gobies, Flat heads, and Flat fishes.

In Teleosts, Ten Pounders, and Tarpons included one species each, the former was *Elops machnata* (Elopidae) and the latter was *Megalops cyprinoides* (Megalopidae). Shads and sardines included 17 species belonging to two families. They were *Anodontostoma chacunda, Dussumieria elopsoides, D. acuta, Escualosa thoracata, Hilsa ilisha, H. kelee, H. toli, Nematalosa nasus, Opisthopterus tardoore, Sardinella fimbriata, S. gibbosa, S. longiceps* (Clupeidae), *Ilisha elongata, I. megaloptera, I. melastoma, Pellona ditchela*, and *Raconda russeliana* (Pristigasteridae). Anchovies included nine species and all belonging to only one family, Engraulidae. They were *Coilia dussumieri, Setipinna taty, Stolephorus bataviensis, S. commersonnii, S. devisi, S. indicus, Thyrssa dussumieri, T. mystax*, and *T. setirostris*. Wolf herrings included two species, *Chirocentrus dorab* and *C. nudus*, both belonging to Chirocentridae. Milk fish was represented by a single species, *Chanos chanos* which belonged to Chanidae. Lizard fishes included four species, *Saurida gracilis, S. tumbil, S. undosquamis*, and *Trachinocephalus myops*, all belonging to Synodontidae. Bombay Duck was represented by a single species, *Harpadon nehereus* which belonged to Synodontidae. Cat fishes included four species belonging to two families. They were *Tachysurus dussumieri, T. tenuispinis, T. thalassinus* (Ariidae), and *Macrones gulio* (Bagridae). Cat fish eels included two species, *Plotosus anguillaris* and *P. canius*, both belonging to Plotosidae. Eels and congers were represented by four species which belonged to two families. They were *Anguilla bicolor bicolor*, *A. nebulosa nebulosa* (Anguillidae), *Muraenesox talabonoides*, and *M. cinereus* (Myraenesocidae). Gar fishes and Half beaks were represented by one species each, the former was represented by *Strongylura crocodilus* (Belonidae) while the latter was represented by *H. marginatus* (Hemiramphidae). Flying fishes, Flute mouths and Barracudas were represented by two species each; the first type was represented by *Cypselurus cyanopterus* and *Exocoetus volitans* (Exocoetidae), the second type by *Fistularia petimba* and *F. villosa* (Fistularidae) and the last type by *Sphyraena jello* and *S. obtusata* (Sphyraenidae). Mullets included three species, *Liza tade, Mugil cephalus*, and *Valamugil cunnesius*, all three species belonged to Mugilidae family. Thread fins included four species, *Eleutheronema tetradactylum, Polynemus indicus, P. sexfilis*, and *P. sextarius*, all belonged to Polynemidae family. Sea perches were represented by a single species, *Lates calcarifer* which belonged to Latidae. Reef cods included three species, *Epinephelus areolatus, E. diacanthus* and *E. tauvina*, all three belonged to Serranidae. Tiger Perches were represented by two species, *Terapon jarbua* and *T. theraps* which belonged to Terapontidae. Bull eyes represented two species, *Priacanthus cruentatus* and *P. hamrur*, both belonged to Priacanthidae family. Whitings included two species, *Sillago sihama* and *S. maculata* which belonged to Sillaginidae family. White fishes and Cobias were represented by one species each, the former by *Lactarius lactarius* and the latter by *Rachycentron canadus*. Carangids included 12 species, *Alectis indicus, Aepes djedaba, Carangoides malabaricus, Caranx ignobilis, Decapterus russelli, D. dayi, Megalaspis cordyla, Scomberoides commersonnianus, S. lysan, S. tala, S. tol*, and *Trachinotus blochii*, all belonged to Carangidae family. Moon fishes and Dolphin fishes included one species each, the former was *Mene maculata* (Menidae family) and the latter was *Coryphaena hippurus* (Coryphaenidae family). Snappers included two species, *Lutjanus argentimaculatus* and *L. johnii* belonging to Lutjanidae. Thread fin breams included three species, *Nemipterus delagoae, N. japonicas*, and *N. mesoprion*, all three belonged to Nemipteridae family. Triple tails was represented by *Lobotes surinamensis* which belonged to Lobotidae family. Silver bellies included seven species, *Gazza minuta, Leiognathus bindus, L. dussumieri, L. equulus, L. splendens, Secutor insidiator*, and *S. ruconius*, all belonged to Leiognathidae family. Mojarras and Grunters, each were represented by two species; the former by *Gerres filamentosus* and *Pentaprion longimanus* (Gerreidae) while the latter by *Pomadasys hasta* and *P. maculatus* (Haemulidae). Croakers included nine species, *Atrobucca nibe, Johnieops vogleri, J. carutta, J. dussumieri, Kathala axillaris, Nibea maculata, Otolithes ruber, Pennahia macrophthalmus*, and *Protonibea diacanthus*, all belonged to Sciaenidae family only. Goat fishes included three species, *Upeneus sulphureus, P. sundaicus*, and *U. vittatus*, all belonged to Mullidae family. Sickle fishes and Butter fishes included one species each, the former was *Drepano punctata* (Drepanenidae) and the latter was *Scatophagus argus* (Scatophagidae). Ribbon fishes included three species, *Trichiurus lepturus, T. russelli* and *Lepturacanthus savala*, all belonged to Trichiuridae family. Tunas, Mackerels and Seer fishes were represented by Scombridae family. Tunas included five species, *Auxis thazard, Euthynnus affinis, Katsuwonus pelamis, Thunnus albacores*, and *T. tonggol*; Mackerels included two species, *Rastrelliger faughni* and *R. kanagurta* and Seer fishes included four species, *Scomberomorus commerson, S. guttatus, S. koreanus*, and *S. lineolatus*. Sail fishes included two species, *Istiophorus platypterus* and *Makaira indica* (Istiophoridae). Sword fish was represented by a single species, *Xiphias gladius* (Xiphiidae). Pomfrets included three species, *Pampus argenteus, P. chinensis* (Stromateidae), and *Parastromateus niger* (Carangidae). Drift fishes, Hump heads, Gobies, and Flat heads, each was represented by one species, *Psenes indicus* (Nomeidae), *Kurtus indicus* (Nomeidae), *Trypauchen vagina* (Oxudercidae) and *Platycephalus indicus* (Platycephalidae). Flat fishes included four species, *Psettodes erumei*, *P. arsius* (Paralichthyidae), *Cynoglossus macrolepidotus* (Cynoglossidae), and *Echeneis naucrates* (Echeneidae).

In Shell fishes, crustaceans included 30 species which represented 10 families while molluscs included 10 species which represented seven families. The crustaceans represented Penaeids, Non-penaeids, Lobsters, Crabs, and Stomatopods while molluscs represented Bivalves and Cephalopods. Penaeids included 17 species which represented three families. They were *Solenocera crassicornis, S. hextii* (Solenoceridae), *Metapenaeus affinis, M. brevicornis, M. dobsoni, M. monoceros, Parapenaeopsis hardwickii, P. acclivirostris, P. sculptilis, P. stylifera, Penaeus indicus, P. japonicus, P. merguiensis, P. monodon, P. semisulcatus, Trachypenaeus curvirostris* (Penaeidae), and *Pandalus borealis* (Pandalidae). Non-penaeids included five species which represented three families. They were *Acetes indicus* (Sergestidae), *Macrobrachium malcolmsonii, M. rosenbergii, Nematopalaemon tenuipes* (Palaemonidae), and *Exhippolysmata ensirostris* (Lysmatidae). Lobsters included three species, *Panulirus homarus, P. polyphagus* (Palinuridae), and *Thenus orientalis* (Scyllaridae). Crabs included four species, *Scylla serrata, Portunus sanguinolentus, P. pelagicus, Charybdis cruciata* (Portunidae). Stomatopods included one species, *Oratosquilla nepa* (Squillidae).

In Molluscs, Bivalves included six species belonging to five families: *Anadara granosa* (Arcidae), *Perna indica, P. viridis* (Mytilidae), *Placuna placenta* (Placunidae), *Crassostrea madrasensis* (Ostreidae), *Meretrix meretrix* (Veneridae).

Cephalopods included four species, *Sepia aculeata, S. pharaonis, Sepiella inermis* (Sepiidae), and *Loligo duvauceliii* (Loliginidae).

The fin and shell-fish species listed in table 1 were found to be used according to their availability; some species are seasonal while some others are aseasonal. Field observations and personal queries with locals across the coastline of Andhra Pradesh indicated that some species are common, some others are uncommon and still some others are rare. Further, some species are of local value while some others are of export value indicating that marine fishery resources are important as seafood, employment provider, and foreign exchange earner.

Common marine fin- and shell-fish species landing/sold at Fishing Harbour and local fish markets of Visakhapatnam: At Fishing Harbour and local markets of Visakhapatnam, twenty marine species were commonly captured and sold depending on their availability. The cartilaginous fishes (Elasmobranchs) included one species, *Himantura bleekeri* (Dasyatidae). Bony fishes (Teleosts) included 18 species belonging to 13 families. They were *Lutjanus argentimaculatus* (Latjanidae), *Johnius dussumieri* (Sciaenidae), *Tachysurus thalassinus* (Ariidae), *Stolephorus commersonii* (Engraulidae), *Trichiurus lepturus* (Trichiuridae), *Lates calcarifer* (Latidae), *Rastrelliger kanagurta, Scomberomorus commerson, S. guttatus, Katsuwonus pelamis, Thunnus albacares* (Scombridae), *Coryphaena hippurus* (Coryphaenidae), *Makaira indica* (Istiophoridae), *Xiphias gladius* (Xiphiidae), *Pampus argenteus, P. chinensis* (Stromateidae), *Parastromateus niger* (Carangidae), and *Muraenesox talabonoides* (Muraenesocidae). One mollusc species, *Sepia pharaonis* (Cephalopod: Sepiidae family) was commonly sold (Tab. 2). All twenty species are shown in figures 2-7.

Figure 2a: *Lutjanus argentimaculatus*, b. *Johnius dussumieri*, c. *Tachysurus thalassinus*.

Figure 3a: *Stolephorus commersonnii*, b. *Trichiurus lepturus*, c. *Lates calcarifer*, d. *Rastrelliger kanagurta*.

Figure 4a: *Scomberomorus commerson*, b. *Scomberomorus guttatus*.

Figure 5a: *Katsuwonus pelamis,* b. *Thunnus albacares,*
c. *Coryphaena hippurus,* d. *Makaira indica*.

Figure 6a: *Xiphias gladius,* b. *Pampus argenteus,*
c. *Pampus chinensis,* d. *Parastromateus niger*.

Figure 7: a. *Muraenesox talabonoides,*
b. *Himantura bleekeri,* c. *Sepia pharaonis*.

According to IUCN Red List Species status globally, the twenty marine species belonged to four categories, Not Evaluated, Data Deficient, Least Concern and Near Threatened. Not evaluated (NE) indicates that IUCN has not yet assessed the species status. Data Deficient (DD) indicates that available information is not sufficient for a proper assessment of the conservation status of the species. Least Concern (LC) indicates that the species is not being a focus of species conservation and do not qualify as threatened, near threatened or conservation dependent. Near Threatened (NT) indicates that the species does not currently qualify for the threatened status but may be considered threatened with extinction in the near future. The NE category included *Himantura bleekeri, Tachysurus thalassinus, Rostrelliger kanagurta, Pampus argenteus, P. chinensis*, and *Muraenesox talabonoides*. The DD category included *Scomberomorus guttatus, Makaira indica*, and *Sepia pharaonis*. The LC category included *Lutjanus argentimaculatus, Johnius dussumieri, Stolephorus commersonnii, Trichiurus lepturus, Lates calcarifer, Katsuwonus pelamis, Coryphaena hippurus, Xiphias gladius*, and *Parastromateus niger*; the last two species populations have been stated to be decreasing globally. The NT category included *Scomberomorus commerson* and *Thunnus albacares*.

Table 2: Common marine fin fish and shell-fish species landing at Visakhapatnam Fishing Harbour/local markets.

S. No.	Family	Scientific name	Common name	Local name	Biotype complex	Feeding habitat	Fish importance	Approx. price/kg
Fin fishes								
Elasmobranchs								
1	Dasyatidae	*Himantura bleekeri* (Blyth, 1860)	Whiptail sting ray	Mullu Tekku	Marine Brackish Benthopelagic Amphidromous	Carnivore (small crustaceans bottom living invertebrates)	Local value	120 Indian Rupee (INR) 1.63 USD
Teleosts								
2	Lutjanidae	*Lutjanus argentimaculatus* (Forsskal, 1775)	Mangrove red snapper	Yerra goraka/ Ratigoraka	Marine Freshwater Reef Associated Oceanodromous	Carnivore (fish crustaceans)	Local value	480 INR 12 USD
3	Sciaenidae	*Johnius dussumieri* (Cuvier, 1830)	Beard croaker	Geddam gorssa	Marine Brackish Demersal Oceanodromous	Carnivore (invertebrates, small fishes)	Local value	150 INR 2.0 USD
4	Ariidae	*Tachysurus thalassicnus* (Ruppel, 1837)	Cat Fish	Tella jella	Demersal Oceanodromous	Carnivore (crustaceans molluscs)	Local value	230 INR 3.14 USD
5	Engrauli-dae	*Stolephorus comersonnii* (Lacepede, 1803)	Commersons anchovy	Nethallu	Marine Brackish Pelagic-neritic Anadromous	Carnivore (surface phytoplankton prawn larvae)	Local value	200 INR 17 USD
6	Trichiuridae	*Trichiurus lepturus* (Linnaeus, 1758)	Ribbon Fish	Pattisavada	Marine Brackish Benthopelagic Amphidromous	Carnivore (surface planktonic crustaceans small fishes)	Export value	180 INR 12.8 USD
7	Latidae	*Lates calcarifer* (Bloch, 1790)	Giant sea perch	Pandugoppa/ Pandumoyya	Marine Freshwater Brackish Demersal Catadromous	Carnivore (fish crustaceans)	Export value	450 INR 1.97 USD
8	Scombridae	*Rastrelliger kanagurta* (Cuvier, 1816)	Indian mackerel	Kanagaorta	Marine Pelagic-neritic Oceanodromous	Carnivore (phytoplankton zooplankton small shrimps fish)	Export value	200 INR 2.8 USD

Table 2 (continued): Common marine fin fish and shell-fish species landing at Visakhapatnam Fishing Harbour/local markets.

9	Scom-bridae	*Scombero morus commer-son* (Lacepede, 1800)	Narrow barred seerfish	Konemu	Marine Pelagic-neritic Oceano-dromous	Carnivore (small fish)	Export value	900 INR 12.29
10	Scom-bridae	*Scombe-romorus guttatus* (Bloch and Schneider, 1801)	Indo pacific seer fish	Vanja-ramu	Marine Brackish Pelagic-neritic Oceano-dromous	Carnivore (small fish, squids, crustaceans)	Export value	650 INR 8.87 USD
11	Scom-bridae	*Katsu-wonus pelamis* (Linnaeus, 1758)	Skip Jack Tuna	Namala soora	Marine Pelagic-oceanic Oceano-dromous	Carnivore (fish, crustaceans, molluscs cephalopods	Export value	160 INR 2.18 USD
12	Scom-bridae	*Thunnus albacares* (Bonna-terre 1788)	Yellow Fin Tuna	Recca soora	Marin Brackish Pelagic-oceanic Oceano-dromous	Carnivore (fish, crustaceans, squids)	Export value	200 INR 2.73 USD
13	Corypha-enidae	*Corypha-ena hippurus* (Linnaeus, 1758)	Mahi Mahi	Abhilasha cheppa	Marine Brackish Pelagic-neritic Oceano-dromous	Carnivore (zoo-plankton, fishes, crustaceans)	Export value	290 INR 3.96 USD
14	Istio-phoridae	*Makaira indica* (Cuvier, 1832)	Black Marlin	Nalla kommu konemu	Marine Pelagic-oceanic Oceano-dromous	Carnivore (small fish, crustaceans, cephalo-pods)	Export value	260 INR 3.55 USD
15	Xiphii-dae	*Xiphias gladius* (Linnaeus, 1758)	Sword fish	Kommu konemu	Marine Pelagic-oceanic Oceano-dromous	Carnivore (small fish, crustaceans, squids)	Export value	280 INR 3.82 USD
16	Stroma-teidae	*Pampus argenteus* (Euphra-sen, 1788)	Silver pomfret	Tella chanduva	Marine Benthopelagic Oceano-dromous	In-shore species (fish eggs, ctenophores, salps, medusa, zoo-plankton)	Export value	700 INR 9.56 USD
17	Stroma-teidae	*Pampus chinensis* (Euphra-sen, 1788)	Chinese pomfret	Attukoyya / Atukula chanduva	Marine Brackish Benthopelagic Amphidro-mous	Carnivore (fish eggs, ctenophores salps medusa zoo-plankton)	Local value	500 INR 6.83 USD

Table 2 (continued): Common marine fin fish and shell-fish species landing at Visakhapatnam Fishing Harbour/local markets.

18	Caran-gidae	*Parastromateus niger* (Bloch, 1795)	Black pomfret	Nalla chanduva	Marine Brackish Reef associated Amphidro-mous	Carnivore (fish eggs, ctenophores, salps, medusa, zoo-plankton)	Local value	280 INR 3.81 USD
19	Muraenesocidae	*Muraenesox talabonoides* (Bleeker, 1853)	Indian pike conger	Tella Pamu cheppa	Marine Brackish Bathy-demersal Amphidro-mous	Carnivore (bottom fish, crustaceans)	Local value	130 INR 1.77 USD
Shell fishes								
Molluscs: Cephalopods								
20	Sepiidae	*Sepia pharaonis* (Ehrenberg, 1831)	Cuttle fish	Charala kalvinda	Benthic Oceano-dromous	Carnivore (cannibal-lism crustaceans cephalo-pods)	Export value	600 INR 8.17 USD

Spawning migration classification of common marine fin- and shell-fish species landing/sold at Fishing Harbour and local fish markets of Visakhapatnam: These marine species were classified based on spawning migration into anadromous, catadromous, amphidromous and oceanodromous. Anadromous and catadromous types included one species each, the former was represented by *Stolephorus commersonnii* while the latter was represented by *Lates calcarifer*. Amphidromous type included five species, *Himantura bleekeri*, *Trichiurus lepturus*, *Pampus chinensis*, *Parastromateus niger*, and *Muraenesox talabonoides*. Oceanodromous type included 13 species which included *Lutjanus argentimaculatus*, *Johnius dussumieri*, *Tachysurus thalassinus*, *Rastrelliger kanagurta*, *Scomberomorus commerson*, *S. guttatus*, *Katsuwonus pelamis*, *Thunnus albacares*, *Coryphaena hippurus*, *Makaira indica*, *Xiphias gladius*, *Pampus argenteus*, and *Sepia pharaonis* (Tab. 2; Fig. 1).

Biotype complex, feeding habit, local and export value, and price value of common marine fin- and shell-fish species landing/sold at Fishing Harbour and local fish markets of Visakhapatnam: All twenty marine species are carnivores and the food items vary with each species. The food items included crustaceans, molluscs, fish eggs, small fish, phytoplanktons, and zooplanktons. The fish species such as *Trichiurus lepturus, Lates calcarifer, Rastrelliger kanagurta, Scomberomorus commerson, S. guttatus, Katsuwonus pelamis, Thunnus albacares, Coryphaena hippurus, Makaira indica, Xiphias gladius*, and *Pampus argenteus*, and the cephalopod molluscan, *Sepia pharaonis* were found to be of export value while all other species were found to be of local value and they are regularly purchased by locals (Figs. 8a-c). The price value of each species in local currency as well as U.S. Dollar currency is recorded in table 2.

Figure 8a: Fish vendors and consumers at the market Visakhapatnam market;
8b, c Visakhapatnam Fishing Harbour market.

The fishermen use sun-drying methods involving fish drying on the boat roof top (Fig. 9a), fish drying by hanging (Fig. 9b) and fish drying on the floor (Fig. 9c) of the fishing harbour market. The dried fish are loaded into bamboo baskets and transported to local markets where fish vendors buy and sell them as a regular livelihood source (Figs. 10a-c).

Figure 9: Visakhapatnam Fishing Harbour – sun-drying method –
a. Drying on the boat roof top, b. Drying by hanging fish, c. Drying on the floor.

Figure 10: Visakhapatnam fishing harbour – a. Bamboo baskets loaded with dried fish,
b. Dried fish being loaded into bamboo baskets,
c. Bamboo baskets loaded with dried fish ready for transport to local markets.

Figure 11: a. Seafood Export Trading Centre, Visakhapatnam,
b. Fish packing being done for export.

Six local companies are involved in exporting edible marine fish and molluscan species to other countries through Visakhapatnam Sea Food Export Trade Center (VSFETC) (Figs. 11a, b). The companies are SMSEA Corporation, SVR Sea Food Private Limited, Ghan Marine Products, Global Marine Products, APS Sea Foods and Southern Sea Foods Exports. The fish species exported through VSFETC are *Trichiurus lepturus*, *Katsuwonus pelamis*, *Thunnus albacares*, *Makaira indica*, *Xiphias gladius*, and *Rastrelliger kanagurta*. The crustacean penaeids exported through VSFETC are *Penaeus monodon*, *P. indicus*, *P. semisulcatus*, and *Pandalus borealis*. In molluscans, the cephalod species, *Sepia pharaonis* is the only species exported through VSFETC. The fish species, *Lates calcarifer*, *Scomberomorus commerson*, *S. guttatus*, *Coryphaena hippurus*, and *Pampus argenteus* despite their export value are not being exported due to heavy consumption locally (Tab. 3).

Table 3: Marine species exported through Visakhapatnam Sea Food Export Trade Center.

SMSEA Corporation			
Species	N (days)	Range (kg)	M ± SD (kg)
Sepia pharaonis	15	4,045.90	1,512.21 ± 985.51
Trichiurus lepturus	15	8,089.66	1,737.36 ± 2,258.91
Katsuwonus pelamis	15	6,350.29	1,657.50 ± 2,181.74
Thunnus albacares	15	6,350.29	846.23 ± 1,703.94
Makaira indica	15	2,431.26	175.42 ± 626.18
Xiphias gladius	15	6,350.29	638.12 ± 1,729.47
SVR Sea Food Private Limited			
Sepia pharaonis	15	3,628.74	1,059.90 ±1050.47
Trichiurus lepturus	15	2,267.96	686.74 ± 704.52
Penaeus indicus	15	2,267.96	838.89 ± 845.73
Pandalus borealis	15	907.19	241.81 ± 288.26
Ghan Marine Products			
Sepia pharaonis	15	410.00	134.00 ± 144.46
Trichiurus lepturus	15	300.00	45.87 ± 92.97
Katsuwonus pelamis	15	2,540.12	730.08 ± 998.80
Thunnus albacares	15	300.00	26.67 ± 79.88
Global Marine Exports			
Pandalus borealis	26	9,932.62	2,883.92 ± 2,128.76
APS Sea Foods			
Sepia pharaonis	15	684	591 ± 195
Trichiurus lepturus	15	2,500	604 ±743
Katsuwonus pelamis	15	6,700	2,007 ± 2,118
Thunnus albacares	15	2,500	856 ± 957
Makaira indica	15	86	11 ± 26
Xiphias gladius	15	50	8 ± 17
Rastrelliger kanagurta	15	180	28 ± 59
Southern Sea Foods Exports			
Pandalus borealis	15	578	324 ± 152
Penaeus monodon	15	90	70 ± 24
Penaeus indicus	15	240	67 ± 56
Penaeus semisulcatus	15	75	36 ± 17

Gears used for capturing common marine fin- and shell-fish species landing/sold at Fishing Harbour and local fish markets of Visakhapatnam: Gears used for capturing the common marine species landing at Fishing Harbour and local markets of Visakhapatnam included eight categories mentioned in the International Standard Statistical Classification of Fishing Gear (ISSCFG, 2016). The categories were Surrounding nets, Seine nets, Trawls, Lift nets, Gillnets, Entangling nets, Traps, Hooks, Lines, and Miscellaneous Gear. The Surrounding Net Gear category was represented by Purse seine; Seine net Gear category by boat seines, seine nets, and beach seines; Trawls category by trawl nets and bottom trawls; Lift nets category by lift nets; Gillnets and Entangling nets category by gillnets, drift gillnets and set gillnets; Traps category by Bamboo skate traps and traps; Hooks and Lines category by hand lines, long lines, trolling lines, pole and lines; and Miscellaneous gear category (not classified with the above groups) by bag nets, dip nets, and harpoons. The Gears used varied with the fish species and the gear types are recorded in table 4. In the same table, the period of occurrence, depth of occurrence (in meters), size at maturity and spawning season are also noted. *Xiphias gladius* is the only species that occurs commonly throughout the year while all other species occur from three to 10 months. All twenty marine species occur at different depths and the depth of occurrence ranged from 0 to 2,870 m. Among these species, *Xiphias gladius* is the largest in size at maturity. The size of other fish/molluscan species at maturity varied from 7 to 250 cm. *Lutjanus argentimaculatus*, *Johnius dussumieri*, *Trichurus lepturus*, *Katsuwonus pelamis*, and *Xiphias gladius* spawn throughout the year while all other species are seasonal in spawning.

Description of morphometrics of common marine fin- and shell-fish species landing/sold at Fishing Harbour and local fish markets of Visakhapatnam: The standard length, total length, depth of body, head length (in cm) and weight (in g) were recorded for teleosts, *Lutjanus argentimaculatus*, *Johnius dussumieri*, *Tachysurus thalassinus*, *Stolephorus commersonii*, *Trichiurus lepturus*, *Lates calcarifer*, *Rastrelliger kanagurta*, *Scomberomorus commerson, S. guttatus, Katsuwonus pelamis, Thunnus albacares, Coryphaena hippurus*, *Makaira indica*, *Xiphias gladius*, *Pampus argenteus*, *P. chinensis*, *Parastromateus niger*, and *Muraenesox talabonoides*. Disc length, total length (in cm) and weight (in g) were recorded for the elasmobranch, *Himantura bleekeri* while mantle length, total length (in cm) and weight (in g) were recorded for cephalod molluscan, *Sepia pharaonis* (Tabs. 5 and 7).

Table 4: Gears used for fish capture, peak period of occurrence, depth of occurrence, size at maturity and spawning season of most common marine fin fish and shell-fish species landing at Visakhapatnam Fishing Harbour.

Sp. no.	Species	Gears used for capturing	Peak period of occurrence	Depth of occurrence (range in m)	Size at maturity (cm)	Spawning season
1.	*Lutjanus argentimaculatus*	Hand lines Long lines Trawl nets	September-January	1-12	50-57	Year-long
2.	*Johnius dussumieri*	Trawl net Boat seines	October-March	30-70	11-16.5	Year-long
3.	*Tachysurus thalassinus*	Skate traps Bag nets Dip nets	March-June September-October	10-80	33-45	April-August
4.	*Stolephorus commersonnii*	Skate nets Boat seines Seine nets	October-April	0-50	7-7.3	March-May
5.	*Trichiurus lepturus*	Trawl nets Bag nets	July-April	100-350	63.9-69.3	Year-long
6.	*Lates calcarifer*	Trawl nets Gill nets Seine nets Hand lines Traps	August-February	10-40	29-60	February-March June-August October-December
7.	*Rastrelliger kanagurta*	Beach seines Drift gillnets Purse seines Trolling nets	August-November	20-90	20-24.5	January-March August-October
8.	*Scomberomorus commerson*	Drift gillnets Trolling lines Hand lines	October-December	10-70	55-82	January-September
9.	*Scomberomorus guttatus*	Drift gillnets Trawl nets Purse seines Trolling nets	October-December	15-200	48-52	January-August April-May

Table 4 (continued): Gears used for fish capture, peak period of occurrence, depth of occurrence, size at maturity and spawning season of most common marine fin fish and shell-fish species landing at Visakhapatnam Fishing Harbour.

Sp. no.	Species	Gears used for capturing	Peak period of occurrence	Depth of occurrence (range in m)	Size at maturity (cm)	Spawning season
10.	*Katsuwonus pelamis*	Purse seines Gill nets Bamboo skate Traps Lift nets	October-May	0-260	40-45	Year-long
11.	*Thunnus albacares*	Purse seines Pole and lines Trolling nets Gill nets	October-January	1-250	78-158	March-May
12.	*Coryphaena hippurus*	Trolling nets Long lines Purse seines Drift gillnets	June-October	0-85	35-93.1	March-September
13.	*Makaira indica*	Long lines Set gillnets	March-September	0-915	–	March-June
14.	*Xiphias gladius*	Long lines Trolling nets	Throughout the year	0-2870	156-250	Year-long Peak: March-June
15.	*Pampus argenteus*	Trawl nets Gillnets	August-January	Inshore 5-80	18-23.5	January-June
16.	*Pampus chinensis*	Trawl nets Gill nets	August-December	0-80	22.5-26.5	January-May
17.	*Parastromateus niger*	Trawl nets Gill nets	August-December	15-40	22-24	February-April
18.	*Muraenesox talabonoides*	Long lines Trawl nets Drift nets	July-September	800-875	122-125	April-May September-October
19.	*Himantura bleekeri*	Long lines Harpoons Bottom trawls Gill nets	December-May	30-40	–	Ovoviviparous
20.	*Sepia pharaonis*	Trawl nets	September-January	0-130	12-24.4	October-November February-March

Table 5: Morphometric characteristics of common marine fin fish and shell-fish species landing at Visakhapatnam Fishing Harbour.

Sp. no.	Species	Standard length (cm) N = 10		Total length (cm) N = 10		Body depth (cm) N = 10		Head length (cm) N = 10		Weight (g) N = 10	
		Range	M ± SD	Range	M ± SD	Range	M ± SD	Range	M±SD	M±SD	M±SD
1.	*Lutjanus argentimaculatus*	14.50-17.50	16.17±0.99	16.80-20.30	18.42±1.21	23.00-27.80	24.85±1.60	4.80-5.90	5.31±0.39	150.0-250.00	178.50±31.45
2.	*Johnius dussumieri*	62.20-109.20	86.14±22.43	79.70-133.30	106.04±26.36	5.00-11.90	8.55±3.14	6.80-12.20	9.57±2.59	240.0-2400.00	1124.00±920.07
3.	*Tachysurus thalassinus*	11.50-14.20	12.78±0.92	14.00-17.10	15.54±0.93	2.80-3.80	3.47±0.30	2.50-3.50	3.24±0.30	18.0-35.0	25.90±4.82
4.	*Stolephorus commersonnii*	52.50-56.20	54.90±1.10	65.20-69.30	68.57±1.23	6.80-7.30	7.04±0.20	10.50-11.20	11.01±0.24	25.00-280.00	224.50±78.33
5.	*Trichiurus lepturus*	147.30-163.30	153.45±4.62	175.70-187.90	178.98±3.40	18.20-23.00	20.53±1.52	15.80-16.80	16.36±0.36	4100.00-6200.00	5230.00±603.78
6.	*Lates calcarifer*	18.00-22.00	19.82±1.17	22.00-25.00	23.31±0.92	5.70-7.00	6.14±0.45	2.30-3.20	2.60±0.30	320.00-450.00	362.00±43.92
7.	*Rastrelliger kanagurta*	149.30-165.10	156.06±5.64	67.50-184.10	164.82±34.43	10.80-14.70	12.83±1.12	10.90-13.00	12.14±0.55	2700.00-4700.00	3410.00±611.83
8.	*Scomberomorus commerson*	35.00-38.00	36.64±1.21	41.00-46.00	43.57±2.23	7.50-8.50	8.03±0.29	9.10-9.80	9.31±0.19	400.00-550.00	550.00±84.98

Table 5 (continued): Morphometric characteristics of common marine fin fish and shell-fish species landing at Visakhapatnam Fishing Harbour.

Sp. no.	Species	Standard length (cm) N = 10		Total length (cm) N = 10		Body depth (cm) N = 10		Head length (cm) N = 10		Weight (g) N = 10	
		Range	M ± SD	Range	M ± SD	Range	M ± SD	Range	M±SD	M±SD	M±SD
9.	*Scomberomorus guttatus*	37.50-52.50	44.07±5.31	42.80-58.80	49.01±6.07	8.20-17.00	12.91±3.02	10.00-15.80	13.06±2.23	1000.00-4800.00	2490.00±1400.36
10.	*Katsuwonus pelamis*	139.70-154.90	146.83±5.16	162.50-186.60	176.59±6.84	40.00-47.00	42.70±2.63	37.00-40.00	38.30±1.06	56000.00-69000.00	61100.00±4383.05
11.	*Thunnus albacares*	134.10-192.50	165.19±15.82	194.30-242.50	216.29±13.29	12.00-28.50	16.95±5.13	12.00-14.00	12.98±0.69	2000.00-6500.00	3510.00±1386.80
12.	*Coryphaena hippurus*	179.00-203.70	193.42±8.65	231.10-248.90	239.42±6.63	20.20-28.00	22.99±2.81	31.00-34.00	31.97±1.12	19000.00-29000.00	22600.00±3806.43
13.	*Makaira indica*	203.20-236.20	223.99±9.78	252.70-276.80	268.31±7.56	18.00-23.00	20.50±1.65	87.00-89.00	88.40±0.70	61000.00-74000.00	69500.00±3628.59
14.	*Xiphias gladius*	19.70-24.20	22.75±1.60	14.30-19.20	17.73±1.57	3.50-4.80	4.22±0.38	10.20-13.0	11.82±0.91	132.00-292.00	220.50±50.44
15.	*Pampus argenteus*	29.00-34.00	32.08±1.69	24.50-29.50	27.43±1.69	6.00-6.70	6.33±0.24	17.00-21.00	18.75±1.40	720.00-2101.00	1055.00±405.74
16.	*Pampus chinensis*	23.00-26.20	24.56±1.24	19.60-22.40	21.14±1.23	5.40-6.00	5.74±0.20	10.90-12.90	11.48±0.64	252.00-376.00	298.70±50.72

Table 5 (continued): Morphometric characteristics of common marine fin fish and shell-fish species landing at Visakhapatnam Fishing Harbour.

Sp. no.	Species	Standard length (cm) N = 10		Total length (cm) N = 10		Body depth (cm) N = 10		Head length (cm) N = 10		Weight (g) N = 10	
		Range	M ± SD	Range	M ± SD	Range	M ± SD	Range	M±SD	M±SD	M±SD
17.	*Parastromateus niger*	139.70-119.30	126.07±6.35	122.60-144.00	131.05±6.91	10.90-14.00	12.13±0.98	24.00-28.00	25.03±1.22	7000.00-10500.00	8120.00±1079.91
18.	*Muraenesox talabonoides*	139.70-119.30	126.07±6.35	122.60-144.00	131.05±6.91	10.90-14.00	12.13±0.98	24.00-28.00	25.03±1.22	7000.00-10500.00	8120.00±1079.91
19.	*Himantura bleekeri*	48.50-87.50	68.97±14.94	78.40-200.40	132.76±56.34	5000.00-17000.00	10680.00±3904.36	48.50-87.50	68.97±14.94	78.40-200.40	132.76±56.34
20.	*Sepia pharaonis*	3.50-40.00	24.70±12.59	33.60-76.20	59.52±13.52	100.00-1500.00	698.00±466.11	3.50-40.00	24.70±12.59	33.60-76.20	59.52±13.52

Lutjanus argentimaculatus: The mean standard length was 19.71 while the mean total length was 23.60. The mean depth of body was 3.50 while the head length was 6.28. The mean weight was 299.80.

Johnius dussumieri: The mean standard length was 16.17 while the mean total length was 18.42. The mean depth of body was 24.85 while the head length was 5.31. The mean weight was 178.50.

Tachysurus thalassinus: The mean standard length was 86.14 while the mean total length was 106.04. The mean depth of body was 8.55 while the head length was 9.57. The mean weight was 1,124.00.

Stolephorus commersonnii: The mean standard length was 12.78 while the mean total length was 15.54. The mean depth of body was 3.47 while the head length was 3.24. The mean weight was 25.90.

Trichiurus lepturus: The mean standard length was 54.90 while the mean total length was 68.57. The mean depth of body was 7.04 while the head length was 11.01. The mean weight was 224.50.

Lates calcarifer: The mean standard length was 153.45 while the mean total length was 178.98. The mean depth of body was 20.53 while the head length was 16.36. The mean weight was 5,230.00.

Rastrelliger kanagurta: The mean standard length was 19.82 while the mean total length was 23.31. The mean depth of body was 6.14 while the head length was 2.60. The mean weight was 362.

Scomberomorus commerson: The mean standard length was 156.06 while the mean total length was 164.82. The mean depth of body was 12.83 while the head length was 12.14. The mean weight was 3,410.00.

Scomberomorus guttatus: The mean standard length was 36.64 while the mean total length was 43.57. The mean depth of body was 8.03 while the head length was 9.31. The mean weight was 550.00.

Katsuwonus pelamis: The mean standard length was 44.07 while the mean total length was 49.01. The mean depth of body was 12.91 while the head length was 13.06. The mean weight was 2,490.00.

Thunnus albacares: The mean standard length was 146.83 while the mean total length was 176.59. The mean depth of body was 42.70 while the head length was 38.30. The mean weight was 61,100.00.

Coryphaena hippurus: The mean standard length was 165.19 while the mean total length was 216.29. The mean depth of body was 16.95 while the head length was 12.98. The mean weight was 3,510.00.

Makaira indica: The mean standard length was 193.42 while the mean total length was 239.42. The mean depth of body was 22.99 while the head length was 31.07. The mean weight was 22,600.00.

Xiphias gladius: The mean standard length was 223.99 while the mean total length was 268.31. The mean depth of body was 20.50 while the head length was 88.40. The mean weight was 69,500.00.

Pampus argenteus: The mean standard length was 22.75 while the mean total length was 17.73. The mean depth of body was 4.22 while the head length was 11.82. The mean weight was 220.50.

Pampus chinensis: The mean standard length was 32.08 while the mean total length was 27.43. The mean depth of body was 6.33 while the head length was 18.75. The mean weight was 1,055.00.

Parastromateus niger: The mean standard length was 24.56 while the mean total length was 21.14. The mean depth of body was 5.74 while the head length was 11.48. The mean weight was 298.70.

Muraenesox talabonoides: The mean standard length was 126.07 while the mean total length was 131.05. The mean depth of body was 12.13 while the head length was 25.03. The mean weight was 8,120.00.

Himantura bleekeri: The mean disc length was 68.97, the mean total length was 132.76 and the mean weight was 10,680.00.

Sepia pharaonis: The mean mantle length was 24.70, the mean total length was 59.52 and the mean weight was 698.00.

Physico-chemical characteristics of coastal water of Visakhapatnam: Coastal surface water collected at 500 m away from Visakhapatnam harbour was analyzed for certain physico-chemical characteristics showed that the mean pH value was 6.20, the mean salinity value 24.51‰, mean Dissolved Oxygen value 6.13 mg/l, mean Biological Oxygen Demand 2.72 mg/l and mean temperature value 26.15°C. The range and standard deviation values are included in table 6.

Table 6: Physico-chemical characteristics of coastal surface water collected 500 meters away from Visakhapatnam harbour.

Sp. no.	Parameters	Range N = 10	Mean ± SD N = 10
1.	pH	6.10-6.30	6.20 ± 0.07
2.	Salinity (‰)	24.40-24.60	24.51 ± 0.06
3.	Dissolved oxygen (mg/l)	6.00-6.30	6.13 ± 0.08
4.	BOD (mg/l)	2.60-2.80	2.72 ± 0.06
5.	Temperature (°C)	26.00-26.50	26.15 ± 0.14

Morphological characteristics of *Pampus argenteus*: Body colour is silvery white on side and blue to grey on the back. Fins are yellowish with dark edges. Body is very deep and compressed but fairly thick. Caudal peduncle is short, deep, and compressed. Mouth is small, sub-terminal and curved downwards with immobile maxilla which are covered with skin and united with cheek. Teeth are minute, uni-seriate, and flattened with a large central cusp and a toothless palate. Gill membranes are broadly attached to isthmus, while gill rakers are two-three to eight-ten on the first arch. Dorsal fin rays are 38-43 while anal fin rays are 34-43. Pectoral fins are long while pelvic fins are absent. Dorsal and anal fins are approximately equal in length; they originate ahead of mid body but are behind pectoral fin base and preceded by fife-ten low blade like spines which are pointed on both ends. Caudal fin is stiff and forked, and the lower caudal fin is like a lobe. Anterior rays, anal fins, median fins, ventral lobe of caudal fins are elongated and curved in a sickle-shaped manner.

Morphological characteristics of *Pampus chinensis*: Body colour is grey to brown on the back, silver white on the sides and small dots on the body. Fins are yellowish to dusky. Body is very deep. Caudal peduncle is short, deep and compressed without keels. Mouth is small, curved downwards with immobile maxilla covered with skin and united with cheek. Jaw teeth are minute, uni-seriate and flattened with a large central cusp and two smaller cusps and a toothless palate. Gill membranes are broadly attached with isthmus while gill opening is a straight vertical slit covered with a flap of skin. Dorsal fin rays 43 to 50 while anal fin rays are 39-42. Dorsal and anal fins are sub-equal in length, which originate at the level of or behind pectoral fin base and without spines ahead of fins. Pectoral fins are broad while pelvic finds are absent. Caudal fin is broad and slightly forked. Median fin rays create almost a vertical margin at posterior border of the fins.

Morphological characteristics of *Parastromateus niger*: Body colour is uniformly silvery to bluish brown. Fins are with dark edges. Body is deep and compressed. Dorsal and ventral sides of the are body are equally convex. Mouth is terminal with upper jaw unrestricted dorsally and ends below slightly before anterior margin of eye. Both jaws possess a single row of small conical teeth. Gill opening is unrestricted both laterally and ventrally. Dorsal fin with four to five short spines followed by one spine plus 41 and 44 soft rays. Anal fin with two embedded spines followed by one spine plus 35 to 39 soft rays. Profile of second dorsal and anal fins is identical with elevated and broadly rounded anterior lobes. Pelvic fins are absent in individuals larger than 10 cm fork and falcate. Lateral line is weakly arched anteriorly and accompanied by a junction of straight and curved parts below the posterior third of dorsal fin; straight part of lateral line has eight to 19 weak scutes which form a keel on caudal peduncle.

A comparison of the morphological features of the three Pomfret fish species showed that *P. chinensis* have higher values in the measured features indicating that this species has more muscle and more weight. The next fish species in terms of more weight is *P. niger* and finally *P. argenteus*.

Table 7: Morphometric features of three selected Pomfret fish species.

S. no.	Parameters	*Pampus argenteus* N=10		*Pampus chinensis* N=10		*Parastromateus niger* N=10	
		M ± SD	Range	M ± SD	Range	M ± SD	Range
1.	Total length (cm)	19.70-24.20	22.75 ± 1.60	29.00-34.00	32.08 ± 1.69	23.00-26.20	24.56 ± 1.24
2.	Standard length (cm)	14.30-19.20	17.73 ± 1.57	24.50-29.50	27.43 ± 1.69	19.60-22.40	21.14 ± 1.23
3.	Head length (cm)	3.50-4.80	4.22 ± 0.38	6.00-6.70	6.33 ± 0.24	5.40-6.00	5.74 ± 0.20
4.	Body depth (cm)	10.20-13.00	11.82 ± 0.91	17.00-21.00	18.75 ± 1.40	10.90-12.90	11.48 ± 0.64
5.	Weight (g)	132.00-292.00	220.50 ± 50.44	720.00-2101.00	1055.00 ± 405.74	252.00-376.00	298.70 ± 50.72

Protein content in the muscle tissue of *Pampus argenteus, P. chinensis* and *Parastromateus niger*: The total protein content varied in each species. The mean total protein content was 18.28% in *P. argenteus*, 16.24% in *P. chinensis* and 19.58% in *P. niger* (Tab. 8). The range and standard deviation values are presented in table 8.

Table 8: Protein content in the muscle portion of three selected Pomfret fish species.

Species	Total protein (% w/w) (N = 10)	
	Range	Mean ± SD
Pampus argenteus	15.44-20.42	18.28 ± 1.51
Pampus chinensis	14.61-17.88	16.24 ± 0.96
Parastromateus niger	17.61-21.08	19.58 ± 1.43
Analysis method: Indian standard method (IS 7219 – 1973)		

Concentrations of heavy metals in the muscle tissue and gill portions of *Pampus argenteus, P. chinensis* and *Parastromateus niger*: The concentrations of heavy metals, arsenic, cadmium, mercury, and lead in muscle and gill portions of the stated fish species were detected using Inductively Coupled Plasma Mass Spectrometry (ICP MS). LOD value is 0.03 for arsenic and mercury, 0.06 for cadmium and 0.018 for lead. LOQ value is 0.10 for arsenic, cadmium, and mercury, and 0.06 for lead. In the muscle portion of all the three fish species, all four heavy metals were present. In *P. argenteus*, the mean concentration of arsenic was 0.81 mg/kg, of cadmium and mercury, each 0.5 mg/kg and of lead 0.08 mg/kg. In *P. chinensis*, the mean concentration of arsenic was 2.80 mg/kg, of cadmium and mercury, each 0.06 mg/kg and of lead 0.18 mg/kg. In *P. niger*, the mean concentration of arsenic was 2.78 mg/kg, of cadmium 0.06 mg/kg, of mercury 0.05 mg/kg, and of lead 0.08 mg/kg. In the gill portion of all the three fish species, all four heavy metals were present. In *P. argenteus*, the mean concentration of arsenic was 0.72 mg/kg, of cadmium 0.05 mg/kg, of mercury 0.06 mg/kg, and of lead 0.08 mg/kg. In *P. chinensis*, the mean concentration of arsenic was 0.82 mg/kg, of cadmium and mercury, each 0.5 mg/kg and of lead 0.06 mg/kg. In *P. niger*, the mean concentration of arsenic was 1.33 mg/kg, of cadmium and mercury, each 0.05 mg/kg, and of lead 0.32 mg/kg (Tabs. 9-12).

Table 9: Recovery of arsenic, cadmium, mercury, and lead in the muscle portion of three selected Pomfret fish species.

Element	Instrument Name	LOD	LOQ	Sample weight (g)	Spike Conc. mg/kg	Content of metal recovered (Mean Conc.) in Muscle (mg/kg)			Recovery % (has to be in the limits)
						Pampus argenteus	*Pampus chinensis*	*Parastro-mateus niger*	
Arsenic	ICP MS (Agilent model 7800)	0.03	0.10	0.5	0.5	0.81	2.80	2.78	70-120%
Cadmium		0.06	0.10	0.5	0.5	0.05	0.06	0.06	
Mercury		0.03	0.10	0.5	0.5	0.05	0.06	0.05	
Lead		0.018	0.06	0.5	0.5	0.08	0.18	0.08	

ICP MS- Inductively Coupled Plasma Mass Spectrometry; LOD-Limit of Detection; LOQ-Limit of Quantification or Quantitation

Table 10: Recovery of arsenic, cadmium, mercury, and lead in the gill portion of three selected Pomfret fish species.

Element	Instrument Name	LOD	LOQ	Sample weight (g)	Spike Conc. mg/kg	Content of metal recovered (Mean Conc.) in Muscle (mg/kg)			Recovery % (has to be in the limits)
						Pampus argenteus	*Pampus chinensis*	*Parastro-mateus niger*	
Arsenic	ICP MS (Agilent model 7800)	0.03	0.10	0.5	0.5	0.72	0.82	1.33	70-120%
Cadmium		0.06	0.10	0.5	0.5	0.05	0.05	0.05	
Mercury		0.03	0.10	0.5	0.5	0.06	0.05	0.05	
Lead		0.018	0.06	0.5	0.5	0.08	0.06	0.32	

ICP MS- Inductively Coupled Plasma Mass Spectrometry; LOD-Limit of Detection; LOQ-Limit of Quantification or Quantitation

Table 11: Heavy metals concentrations in the muscle portion of three selected Pomfret fish species.

S. no.	Scientific name	Muscle tissue (N=10)							
		Arsenic (mg/kg)		Cadmium (mg/kg)		Mercury (mg/kg)		Lead (mg/kg)	
		Range	M±SD	Range	M±SD	Range	M±SD	Range	M±SD
1.	*Pampus argenteus*	0.58-1.14	0.81 ± 0.18	0.00-0.05	0.05 ± 0.00	0.04-0.09	0.05 ± 0.01	0.04-0.11	0.08 ± 0.01
2.	*Pampus chinensis*	1.87-5.14	2.80 ± 1.24	0.05-0.11	0.06 ± 0.02	0.05-0.12	0.06 ± 0.02	0.07-0.5	0.18 ± 0.12
3.	*Parastromateus niger*	1.85-3.82	2.78 ± 0.65	0.05-0.08	0.06 ± 0.01	0.05-0.05	0.05 ± 0.00	0.05-0.12	0.08 ± 0.03

Table 12: Heavy metals concentrations in the gill portion of three selected Pomfret fish species.

S. no.	Scientific name	Muscle tissue (N=10)							
		Arsenic (mg/kg)		Cadmium (mg/kg)		Mercury (mg/kg)		Lead (mg/kg)	
		Range	M ± SD	Range	M ± SD	Range	M ± SD	Range	M ± SD
1.	*Pampus argenteus*	0.54-0.91	0.72 ± 0.12	0.05-0.05	0.05 ± 0.00	0.05-0.10	0.06 ± 0.02	0.07-0.12	0.08 ± 0.02
2.	*Pampus chinensis*	0.50-1.42	0.82 ± 0.33	0.02-0.09	0.05 ± 0.02	0.05-0.13	0.06 ± 0.03	0.06-0.24	0.15 ± 0.06
3.	*Parastromateus niger*	0.79-2.13	1.33 ± 0.46	0.05-0.07	0.05 ± 0.01	0.05-0.05	0.05 ± 0.00	0.05-1.44	0.32 ± 0.53

Comparison of heavy metal concentrations in muscle/gill portions of Pomfret fish species with the permissible standards set out by different organizations: Heavy metal concentrations detected in muscle and gill portions of all the three Pomfret fish species were compared with the recommended limits permitted by European Union Regulations (EU) 2006, Food and Agriculture Organization (FAO)/World Health Organization (WHO) 2011, Ministry of Agriculture, Fisheries and Food (MAFF) and Food Safety and Standards Authority of India (FSSAI). Standards for arsenic are not available in the regulations of EU (2006), FAO/WHO (2011) and MAFF. According to FSSAI (2011), the concentration of arsenic in muscle and gill portion separately or put together in all the three fish species was highly negligible and far below the recommended limit. For cadmium, according to EU (2006) and FAO (2003) regulations, the recommended limit is 0.05 mg/kg; according to MAFF, the recommended limit is 0.2 mg/kg; and according to FSSAI (2011), the recommended limit is 0.3 mg/kg. The detected concentration of cadmium in the muscle and gill portion of *P. argenteus*, and in the gill portion of *P. chinensis* and *P. niger* was at the recommended limit and in the muscle portion of *P. chinensis* and *P. niger* slightly exceeded the recommended limit set by EU (2006) and FAO (2003) regulations. But the detected concentration of cadmium in the muscle and gills of all the three fish species exceeded the recommended limit set by MAFF and FSSAI (2011). The detected concentration of mercury in the muscle tissue of *P. argenteus* and in the muscles and gills of *P. niger* was within the recommended limit according to EU (2006), FAO/WHO (2011), FAO (2003), MAFF and FSSAI (2011). But the detected concentration of mercury in the gills of *P. argenteus*, muscle and gill portions of *P. chinensis* slightly exceeded the permissible limit set out by all these regulating organizations. The detected concentration of lead in the muscle and gill portion of *P. argenteus, P. chinensis*, and in the muscle portion of *P. niger* were lower than the allowed limit indicated by all these regulating organizations. But the detected concentration of lead in the gill portion of *P. niger* slightly exceeded the allowed limit indicated by EU (2006), FAO/WHO (2011) and FSSAI (2011) and prominently exceeded the allowed limit set out by FAO (2003) and MAFF (Tab. 13).

Table 13: Comparison of heavy metal concentrations analyzed in muscle and gill portions of three selected Pomfret fish species with the permissible standards set out by different organizations.

S. no.	Heavy Metal (mg/kg)	*Pampus argenteus* (N = 10)		*Pampus chinensis* (N = 10)		*Parastromateus niger* (N = 10)		E.U 2006 mg/kg	FAO/WHO 2011 mg/kg	FAO 2003 mg/kg	MAFF mg/kg	FSSAI 2011 mg/kg
		Muscle	Gills	Muscle	Gills	Muscle	Gills					
1	Arsenic	0.81 ± 0.18	0.72 ± 0.12	2.80 ± 1.24	0.82 ± 0.33	2.78 ± 0.65	1.33 ± 0.46	–	–	–	–	76
2	Cadmium	0.05 ± 0.00	0.05 ± 0.00	0.06 ± 0.02	0.05 ± 0.02	0.06 ± 0.01	0.05 ± 0.01	0.05	–	0.05	0.2	0.3
3	Mercury	0.05 ± 0.01	0.06 ± 0.02	0.06 ± 0.02	0.06 ± 0.03	0.05 ± 0.00	0.05 ± 0.00	0.5	0.5	0.5	0.5	0.5
4	Lead	0.08 ± 0.01	0.08 ± 0.02	0.18 ± 0.12	0.15 ± 0.06	0.08 ± 0.03	0.32 ± 0.53	0.3	0.3	0.2	2.0	0.3

E.U: European Union regulations; FAO: Food and Agriculture Organization; WHO: World Health Organization; MAFF: Ministry of Agriculture, Fisheries and Food; FSSAI- Food Safety and Standards Authority of India.

DISCUSSION

Inventory of marine fishery resources of coastline of Andhra Pradesh: The State of Andhra Pradesh has a long coastline of 974 km and a continental shelf area of 33,227 km^2 which is spread over nine coastal districts. This coastline area is the home for a diversity of marine fishery resources comprising of several groups of fishes, crustaceans, molluscs, and other marine organisms. This coastline of Andhra Pradesh is known for a thriving fisheries sector which provides nutritional food to the people and exports surplus seafood to other countries. The fish catches fluctuate greatly from year to year depending on the spawning potential, consumption levels, and pollution factors (Syda Rao et al., 2008). Despite the great potential for fishery resources, there is no consolidated list of fin fishes, crustaceans, and molluscs for the coastline of Andhra Pradesh in order to evaluate the potential of different stations across the coastline to provide seafood for locals, export seafood to other countries and provide livelihood opportunities for fishing community. In this study, an inventory of fishery resources of coastline of Andhra Pradesh prepared based on field study indicated that a total of 212 species consisting of finfishes, crustaceans, and molluscs. Among fin fishes, 26 species belong to Elasmobranch group, 146 species to Teleosts group. The crustaceans comprised of 30 species while molluscs comprised of 10 species. Fin fishes and crustaceans have been found to be the major contributors to fishery sector while the contribution of molluscs to the fishery sector is negligible. Sharks are more speciose than skates and rays among Elasmobranchs while shads, sardines, anchovies, carangids, and croakers are more speciose among Teleosts. Penaeids are more speciose among crustaceans. Among molluscs, bivalves, and cephalods comprised of a few species of which the cephalod, *Sepia pharaonis* is the only species that has commercial and export value.

Common marine fishery resources of Visakhapatnam coast: Muddula Krishna et al. (2016) reported 28 fish species from the Visakhapatnam coastal waters, of which eight species belong to threatened categories of IUCN red list status. In this study, it is found that twenty edible marine species land at the Fishing Harbour and local markets of Visakhapatnam. They are *Himantura bleekeri*, *Lutjanus argentimaculatus*, *Johnius dussumieri*, *Tachysurus thalassinus*, *Stolephorus commersonii*, *Trichiurus lepturus*, *Lates calcarifer*, *Rastrelliger kanagurta*, *Scomberomorus commerson*, *S. guttatus*, *Katsuwonus pelamis*, *Thunnus albacares*, *Coryphaena hippurus*, *Makaira indica*, *Xiphias gladius*, *Pampus argenteus*, *P. chinensis*, *Parastromateus niger*, *Muraenesox talabonoides*, and *Sepia pharaonis*. According to IUCN red list, *S. commerson* and *T. albacares* are classified under Near Threatened category; *S. guttatus, M. indica*, and *S. pharaonis* under Data Deficient category; *H. bleekeri*, *T. thalassinus, R. kanagurta, P. argenteus, P. chinensis*, and *M. talabonoides* under Not Evaluated category; and all other species under Least Concern category. In the last category, *X. gladius* and *P. niger* have been stated as populations are decreasing. Among these twenty species, the species under Near Threatened category although do not qualify for the Threatened Status need to be evaluated from time to time to revise their status. The species under Data Deficient category need sufficient fact-based information for the evaluation of their current status. The species under Not Evaluated category require immediate evaluation of their present status as IUCN has not assessed their status so far. The species under Least Concern category do not need any evaluation for their conservation, however, regular evaluation of these species is a necessity as their populations may dwindle gradually as recorded in case of *Xiphias gladius* and *Parastromateus niger* by IUCN. The present study shows that the populations of these species and accordingly their status are consistently subjected to degradation and fragmentation of their habitats due to unorganized and organized human activities involving urbanization, industrialization and tourism. Further, over-exploitation and over-consumption locally and also seafood exports through Visakhapatnam Sea Food Export Trade Center (VSFETC) contribute to the rapid decline of populations of these species. Therefore, there is an urgent need to evaluate the present status of the edible marine species of Visakhapatnam coastal waters in order to take proper measures for their conservation, management and utilization as food and revenue sources.

Gears used for catching marine fishery resources from Visakhapatnam coast: Sreekrishna (2002) provided the details of different crafts operating to harvest marine fishery resources along the coastline of Andhra Pradesh. Syda Rao et al. (2008) reported that a variety of gears are employed to harvest the coastal and offshore fishery resources of Andhra Pradesh state. These authors noted that the gears in use range from simple cast nets to large seines and trawls. The line fishing is very active for coastal, offshore and oceanic fishes in Andhra Pradesh. These gears are operated from small traditional non-mechanized crafts, motorized crafts and medium to large mechanized crafts depending on the area of operation, targeted fishes and the fish price as well. Immanuel and Syda Rao (2012) reported that long line with 500-600 hooks and hand line with six to ten hooks are important gears used by fishermen involved in harvesting fish from coastal waters of Visakhapatnam. In the present study, the fishermen of the coastline of Visakhapatnam use different gears to harvest marine fishery resources. They belong to Surrounding nets, Seine nets, Trawls, Lift nets, Gillnets and Entangling nets, Traps, Hooks, Lines, and Miscellaneous Gears categories listed in the International Standard Statistical Classification of Fishing Gears (ISSCFG, 2016). They use more than one type of gear for catching each fish species that land at the fishing harbour. But the fishermen use only trawl nets for catching the cephalod molluscan, *Sepia pharaonis*. In general, fishing is carried out year-long but a seasonal trend is evident in using different gears. Fishing is banned from mid-April to mid-May on the operation of mechanized crafts to conserve fishery resources. The traditional crafts using gillnets, seines, and the lines carryout fishing activities throughout the year; however, the fishermen abstain from fishing activity at sea during cyclone warning times as advised by the India Meteorological Department, Government of India. All twenty marine species harvested from the coastal waters of Visakhapatnam occur at different depths which range from 0 to 2,870 m. The fin fish, *Xiphias gladius* is the largest in size at maturity and it is the only species that occurs commonly throughout the year whereas all other species vary in size at maturity from seven to 250 cm and occur for three to ten months for harvest. Of the twenty species, *Lutjanus argentimaculatus*, *Johnius dussumieri*, *Trichurus lepturus*, *Katsuwonus pelamis*, and *Xiphias gladius* spawn throughout the year while all other species spawn seasonally.

Morphometric analysis of marine fishery resources of Visakhapatnam coast: Truman (1999) reported that morphological characters are important in fisheries biology to measure discreteness and relationships among various taxonomic categories. He also stated that phenotypic plasticity in fishes is important to adapt to environmental changes by way of modification of their physiology and behaviour. In effect, the fishes display changes in their morphology, reproduction, or survival in order to mitigate the effects of environmental variation. Rutherford et al. (1987) stated that behavioural and physiological characters of fishes respond quickly to local conditions and fluctuate greatly during an individual's life-span. Crowl and Covich (1990) mentioned that phenotype of individuals of fishes usually does not respond to fluctuating environmental conditions and hence phenotype characters are stable and easily quantifiable. Different authors reported that the length-weight relationships are important among biometric relationships as useful tools in fish biology (Pauly, 1993; King 1995; Petrakis and Stergiou, 1995; Santos et al., 2002; Ferreira et al., 2008). Phenotypic features of fishes such as total length, standard length, head length, depth of the body and weight are important for use as a valid method to identify the specimens of fish collected with their systematic morphology (Karunanidhi et al., 2017). In the present study, keeping the importance of phenotypic features of fishes in view, these features have been measured for all the twenty edible marine species landing at Visakhapatnam fishing harbour. The standard length or total length of these fishes mostly not tallied with the size values of these fishes at their maturity given by Marine Products Exports Development Authority, Kochi, India, and hence, necessitates further study in detail in different pockets of coastal waters along the entire coastline of Andhra Pradesh. Additionally, the morphological characters of three Pomfret species, *Pampus argenteus, Pampus chinensis*, and *Parastromateus niger* are also described in this study because they have been chosen for the assessment of protein content and heavy metal concentrations in their muscle and gill portions. Nevertheless, the morphometric data provided for these species from Visakhapatnam coastal water forms the basis for further studies and is useful to compare with the same species captured at different locations of coastline of not only Andhra Pradesh but also of other coastal states of India. The information resulting from such studies is expected to be useful for evaluating the length-weight relationships and their value in understanding stock composition, growth, life span, production, and mortality (Stergiou and Moutopoulos, 2001).

Migration types, feeding habit and export value of marine fishery resources of Visakhapatnam coast: Tsukamoto et al. (2009) described different types of migrations in fishes. They are potamodromy, oceanodromy, and diadromy; the last type includes catadromy, anadromy, and amphidromy. Potamodromy involves fishes that move and complete their life cycle entirely in fresh water (Bemis and Kynard, 1997). Oceanodromy involves fishes that move and complete their life cycle entirely in sea water (Teo et al., 2007). Diadromy involves fishes that move between freshwater and marine environments at regular periods in their life cycle (McDowall, 1997). In this migration type, the sub-type, catadromy involves fishes that move from fresh water to sea water for spawning. The sub-type anadromy involves fishes that move sea water to fresh water for spawning while the last sub-type amphidromy involves fishes that move freshwater/estuaries to sea water as larvae and return to fresh water to grow into adults and spawn. In each of these forms of diadromy, different fish species use either freshwater or marine environments for parts of their life histories such as spawning, larval and juvenile growth and maturation (McDowall, 1997; Bradbury et al., 2009). In the present study, among the twenty fish species landing at Visakhapatnam fishing harbour, *Stolephorus commersonii* is anadromous, *Lates calcarifer* is catadromous, *Himantura bleekeri*, *Trichiurus lepturus*, *Pampus chinensis*, *Parastromateus niger*, and *Muraenesox talabonoides* are amphidromous, and all other species are oceanodromous indicating that most of the fish species sold locally are strictly oceanic species and do not require freshwater habitat at any stage of their life history and hence there is a huge potential for their continued availability which substantiates the Least Concern status given to most of these species by IUCN. Interestingly, all twenty marine species in this study are carnivores, the feeding habit of which enables them to utilize a wide variety of food items and produce their populations abundantly.

Among the twenty marine species captured from Visakhapatnam coastal waters, several species have been reported to be of export value but only some fin fish species *Trichiurus lepturus*, *Katsuwonus pelamis*, *Thunnus albacares*, *Makaira indica*, *Xiphias gladius*, and *Rastrelliger kanagurta*, and the molluscan, *Sepia pharaonis* are exported by different companies regularly through local trade center. Of these, *T. lepturus*, *K. pelamis*, and *X. gladius* have the Least Concern status, *M. indica* and *S. pharaonis* Data Deficient status, *R. kanagurta* Not Evaluated status and *T. albacares* Near Threatened status according to IUCN Red list. The species with Data Deficient and Not Evaluated status need to be assessed to know their present status to allow or disallow exports and to regulate their catch. The species with Near Threatened status is the main cause of concern as its continued exploitation for local consumption and exports may lead to its extinction in course of time and hence its catch is to be regulated while taking appropriate measures for its conservation, production, and management. Further, the export and local consumption of species with Least Concern status also need to be regulated because their continued exploitation may lead to a change in their status according to the criteria of IUCN.

Physico-chemical characteristics of sea water at Visakhapatnam: Satynarayana et al. (1992) reported on the seasonal variations in physico-chemical parameters in surface harbour waters and coastal waters of Visakhapatnam. The study provided annual averages of pH, salinity, temperature, dissolved oxygen, and biological oxygen demand which indicated that there is an increase in pH and salinity from harbour to coastal waters; the lower pH at harbour is attributed to the drainage of acidic effluents from the nearby industries while the lower salinity at harbour is attributed to the influx of industrial effluents and domestic sewage, and the resultant dilution. Temperature is relatively high in summer and low in winter. The surface water in harbour is super-saturated with dissolved oxygen due to intense photosynthetic activity by several planktonic blooms as reported previously by Ganapati and Raman (1979). The coastal water showed lower values of dissolved oxygen which is attributed to offshore divergence as reported previously by Satyanarayana et al. (1987). Biological oxygen demand is more in the harbour and far less in coastal waters; the high BOD in the harbour is because of moderate pollution. In the present study, the values of pH, salinity, dissolved oxygen, biological oxygen demand and temperature recorded in May from the coastal surface waters 500 m away from the Visakhapatnam harbour almost agree with the values of the same parameters reported for the coastal surface waters of Visakhapatnam by Satynarayana et al. (1992). Since the harbour area of Visakhapatnam is consistently polluted due to influx of various industrial effluents and domestic sewage, it is felt that the values of pH, salinity, temperature, dissolved, oxygen and biological oxygen demand would further go up far beyond the values of the same parameters for harbour surface water reported by Satynarayana et al. (1992). Similarly, Raman (1995) also reported all time high values of dissolved oxygen in harbour surface waters and attributed these values to the periodic outbursts of phytoplanktons, especially *Skeletonema costatum* which use nutrients from industrial and urban wastes. Further, he also stated that pollution-tolerant species such as *Capitella capitata* inhabited the bottom sediments of the harbour that contained a heavy load of organic matter. The increased pollution levels led to the disappearance of stenoecious species which live only in a restricted range of habitats, and they are replaced by other pollution-tolerant species. Therefore, the study suggests that it is imperative to regulate the influx of industrial effluents and domestic sewage into the harbour waters to enable the latter to recover back to its previous state with their native stenoecious species and to maintain the water chemistry of coastal surface waters for the sustainability of marine fishery resources.

Protein content in *Pampus argenteus, P. chinensis* and *Parastromateus niger* collected from coastal waters of Visakhapatnam: Hajeb et al. (2009) reported that fish is a healthy food in contrast to meat, poultry, and eggs for most of the people in the world, especially in developing countries. It provides comparatively cheap and readily available protein sources in addition to long chains of n-3 fatty acids, amino acids and vitamins, and minerals. Sikorski (1990) stated that among all the fishes, marine fish are very important sources of protein and different mineral components. Priatni et al. (2018) analyzed total protein content in nine marine fish species, *Leiognathus equulus, Mystacoleucus padangensis, Nemipterus hexodon, Oxyleotris marmorata*, *Selaroides leptolepis*, *Terapon jarbua*, and *Trichiurus lepturus*; the protein content in these fish species varied from 65 to 86% weight by weight. These authors also reported that total protein content in *Pampus argenteus* was 61.07% weight by weight. In the present study, it is found that the total protein content is only 18.28% in *P. argenteus* (w/w) indicating that its protein content is far less when compared to the total protein content reported for the same species by Priatni et al. (2018); this huge variation could be attributable to the size, age, and food sources available to the species in the habitat where individuals of this species live. Further, the total protein content is also at low level in *P. chinensis* and *P. niger*, it is 16.24% (w/w) in the former and 19.58% (w/w) in the latter. Therefore, the study reveals that the three Pomfret species now analyzed are not very important protein sources. However, further studies on the total protein content in individuals of these Pomfret species with different age and size collected from different locations of coastal waters of Visakhapatnam are required to confirm the findings of the present study.

Heavy metal pollution in gills and muscle of *Pampus argenteus, P. chinensis*, and *Parastromateus niger* collected from coastal waters of Visakhapatnam: Vinodhini and Narayanan (2009) reported that fish gill is an important site for the entry of heavy metals and in fact, it is the first target organ for exposure to heavy metals in coastal water. The concentration of metals in the gill is an indicator of the level of the metals in the water where the fish live while the concentration in liver and kidney represents storage of metals (Romea et al., 1999; Rao and Padmaja, 2000). Since the gill in fishes is the first organ that gets exposed to coastal water, it is usually recommended as an environmental indicator organ of water pollution than any other organs of fishes (Obasohan et al., 2008; Yilmaz, 2009).

In fishes, heavy metal bioaccumulation is species-dependent. Bio-accumulation of heavy metals is related to the bioconcentration capacity of species, their habitats, and feeding habits such as carnivore, herbivore, and omnivore. Further, variations of concentrations of heavy metals in different species is also related to body weight and length, gender, age, and growing rate, body portions analyzed, and physiological conditions. The type and level of water pollution, chemical form of metal in the water, water temperature, pH, dissolved oxygen concentration, water transparency are other factors that influence heavy metal concentrations in different fishes (Al-Majed and Preston, 2000; Canli and Atli, 2003; Yilmaz, 2005; Agoes and Hamami, 2007; Fariba et al., 2009; Raja et al., 2009). In puffer fishes of the Gulf of Mannar Marine Biosphere Reserve, South India, *Takifugu oblongus, Lagocephalus guentheri, Arothron hispidus*, *Chelodan patoca*, and *Arothron immaculatus* the high accumulation of heavy metals is attributed to their carnivorous feeding nature and bottom habitat (Karunanidhi et al., 2017). Water temperature plays an important role in the rate of uptake and elimination of heavy metals and causes differences in metal deposition rates in different organs affecting certain physiological processes. Further, regulatory ability, behaviour and feeding habits play a main role in the accumulation differences in different organs (Nwabunike, 2016).

Arsenic is a naturally available element in soils, water, and living organisms. An acute high-level exposure to arsenic causes vomiting, diarrhea, anemia, liver damage, and death. Long term exposure could cause skin disease, hypertension, some forms of diabetes, and cancer (Centeno et al., 2005). Most arsenic in our diet is present in organic form (WHO, 2011). Most arsenic in marine organisms is in non-toxic organic form and does not constitute a risk for human health (Maher, 1983). In the present study, the detected concentration of arsenic in both muscle and gill portions individually or combined in all the three Pomfret species, *Pampus argenteus, P. chinensis,* and *Parastromateus niger* is highly negligible and far below the recommended limit fixed by FSSAI (2011) and hence is safe for consumption by humans. Set standard limit for arsenic is not fixed in the regulations of EU (2006), FAO/WHO (2011) and MAFF and is not possible to evaluate the detected concentration of arsenic in the three Pomfret species. Nevertheless, the arsenic concentration in these fish species is negligible and totally safe for consumption.

The heavy metals, cadmium, mercury, and lead are non-essential and have no known essential role in living organisms but exhibit extreme toxicity even at very low metal exposure levels and pose great threats to all forms of life especially human health (Eisler, 1985; Jarup, 2003). Toxic effects occur when excretory, metabolic, storage, and detoxification mechanisms are not able to counter the uptake of metals (Obasohan et al., 2008) and the effects result in physiological and histopathological changes (Oliveira Ribeiro et al., 2005; Rajamanickam and Muthuswamy, 2008; Vinodhini and Narayanan 2009; Georgieva et al., 2014). Ingestion of any significant amount of cadmium causes immediate poisoning and damage to liver and kidneys (El-Moshelhy et al., 2014). Cadmium is highly toxic and shows nephrotoxic effects and long-term exposure to this heavy metal causes bone damage (Chaitanya et al., 2017). Lead causes long-term harm in adults in terms of increasing risk of high blood pressure, kidney damage, and neurological problems. In young children, exposure to lead causes toxic effects and they suffer from profound and permanent adverse health effects, particularly related to development of brain and nervous system (Voegborlo et al., 2012). In the present study, the detected concentrations of cadmium and lead in the muscle and gills of the Pomfret species do not fall within the recommended limits set by all the regulating agencies. Cadmium concentration detected in the muscle and gills of *P. argenteus*, in the gills of *P. chinensis*, and *P. niger* is within the permitted limit and in the muscle of *P. chinensis* and *P. niger* slightly exceeded the permitted limit according to EU (2006) and FAO (2003) regulations. But the detected cadmium concentration in both muscle, and gills of all the three fish species is beyond the recommended limit according to MAFF and FSSAI (2011). Mercury concentration in the muscle of *P. argenteus* and in the muscle and gills of *P. niger* is within the recommended limit according to EU (2006), FAO/WHO (2011), FAO (2003), MAFF and FSSAI (2011) while its concentration in the gills of *P. argenteus*, muscle and gills of *P. chinensis* exceeded slightly beyond the permitted limit by all these regulating agencies. Lead concentration detected in the muscle and gills of *P. argenteus, P. chinensis*, and in the muscle of *P. niger* is within the permitted limit according to the regulations of EU (2006), FAO/WHO (2011), FAO (2003), MAFF and FSSAI (2011). But the lead concentration levels in the gills of *P. niger* slightly exceeded the permitted limit according to EU (2006), FAO/WHO (2011), and FSSAI (2011) prominently exceeded the permitted limit according to FAO (2003) and MAFF. The results of the study on the bioaccumulation of heavy metals in the muscle and gill parts of Pomfret species indicate that consuming these fish species from coastal waters of Visakhapatnam is largely not harmful because the levels of heavy metals analyzed are either below or slightly beyond the permissible limits. However, it is important to state that cadmium levels in the muscle of *P. chinensis* and *P. niger*, and mercury levels in the muscle of *P. chinensis* are causes of concern because their muscle portion is the main edible part. The people who consume *P. chinensis* and *P. niger* regularly or frequently are more prone to the health risks associated with high levels of cadmium, and mercury. In general, the bioaccumulation levels of all four heavy metals detected in all the three Pomfret species are either within or slightly in excess of the recommended limits standardized by different national and international agencies. Such low levels of these heavy metals particularly in the muscle portion of these fish species could be attributable to their carnivorous feeding habit and age factor; the finding of this study is in agreement with Khalid (2004) who reported that carnivorous fish accumulate lower levels of heavy metals than herbivorous fish and also with Abdallah (2008) who reported higher metal concentrations in omnivorous or herbivorous fish than carnivorous fish. Further, the higher cadmium levels in the muscle of *P. chinensis* and *P. niger*, and higher mercury levels in the muscle of *P. chinensis* could also be attributable to their migratory nature as these two fish species are amphidromous which requires them to move between freshwater/estuaries and sea water as part of their life cycle during which they get exposed to polluted aquatic environment which is usually associated with freshwater/estuarine areas. The low mercury levels in the muscle of *P. niger* could be attributable to the less mercury pollution in the aquatic environment, especially in freshwater/estuarine areas. *P. argenteus* is an oceanodromous species and migrates within the ocean for feeding and spawning due to which it is not very prone to polluted aquatic environment which is usually the case with freshwater/estuarine areas which are characteristically the reception sites for industrial effluents and domestic sewages/wastes. As a result, *P. argenteus* carries out its life cycle relatively in pollution-free aquatic environment while the other two pomfret species get exposed to polluted aquatic environment, especially in freshwater/estuarine areas. Nevertheless, *P. chinensis* and *P. niger* could be used to evaluate the health condition of the aquatic environment and use them as biomarkers of heavy metal contamination in coastal waters of Visakhapatnam.

The study suggests strategy elements for the conservation and management of marine fishery resources of coastal waters of Andhra Pradesh State. Location-based studies are required to document marine fishery resources, their migration types, feeding habits, their present status according to IUCN criteria and risk of their exposure to marine pollution during their life cycle. Further, studies on heavy metal contamination in each edible marine fish species are required to alert fish consumers and take appropriate actions to control marine pollution. Finally, regular monitoring of marine resources is essential to improve the quality of sea-food against contaminants, especially heavy metals to protect the health of fish consumers and for managing the coastal waters in an ecologically sustainable manner.

CONCLUSIONS

The State of Andhra Pradesh has a long coastline which is spread over nine coastal districts. This coastline area is the home for a diversity of marine fishery resources comprising of several groups of fishes, crustaceans, molluscs, and other marine organisms. An inventory of marine fishery resources of this state indicated that a total of 212 species consisting of fin fishes, crustaceans, and molluscs which have food value. Among fin fishes, 26 species belong to Elasmobranch group, 146 species to Teleosts group. The crustaceans are represented by 30 species while molluscs are represented by 10 species. Fin fishes and crustaceans are the major contributors to fishery sector.

At Fishing Harbour and local markets of Visakhapatnam, a total of twenty edible marine species are commonly sold. They are *Himantura bleekeri*, *Lutjanus argentimaculatus*, *Johnius dussumieri*, *Tachysurus thalassinus*, *Stolephorus commersonii*, *Trichiurus lepturus*, *Lates calcarifer*, *Rastrelliger kanagurta, Scomberomorus commerson, S. guttatus, Katsuwonus pelamis, Thunnus albacares, Coryphaena hippurus, Makaira indica*, *Xiphias gladius*, *Pampus argenteus, P. chinensis*, *Parastromateus niger*, *Muraenesox talabonoides,* and *Sepia pharaonis*. According to IUCN red list, *S. commerson* and *T. albacares* belong to Near Threatened category; *S. guttatus, M. indica,* and *S. pharaonis* to Data Deficient category; *H. bleekeri, T. thalassinus*, *R. kanagurta, P. argenteus, P. chinensis*, and *M. talabonoides* to Not Evaluated category; and all other species belong to Least Concern category. Of these, *S. commersonii* is anadromous, *L. calcarifer* is catadromous, *H. bleekeri, T. lepturus, P. chinensis, P. niger*, and *M. talabonoides* are amphidromous, and all other species are oceanodromous indicating that most of the fish species sold locally are strictly oceanic species and do not require freshwater habitat at any stage of their life history and hence there is a huge potential for their continued availability which substantiates the Least Concern status given to most of these species by IUCN. Interestingly, all twenty marine species in this study are carnivores, the feeding habit of which enables them to utilize a wide variety of food items and produce their populations abundantly. However, the populations of these species are consistently subjected to degradation and fragmentation of their habitats due to unorganized and organized human activities involving urbanization, industrialization, tourism. Further, these species are highly subjected to over-exploitation and over-consumption of these fishery resources locally and for making money through seafood exports through the Visakhapatnam Sea Food Export Trade Center (VSFETC). Keeping this situation in view, it is suggested that there is an urgent need to evaluate the present status of the edible marine species of Visakhapatnam coastal waters in order to take proper measures for their conservation, management and utilization as food and revenue sources.

The fishermen of the coastline of Visakhapatnam use Surrounding nets, Seine nets, Trawls, Lift nets, Gillnets and Entangling nets, Traps, Hooks and Lines, and Miscellaneous Gears categories listed in the International Standard Statistical Classification of Fishing Gears (ISSCFG 2016) to harvest marine fishery resources. In general, fishing is carried out year-long but, a seasonal trend is evident in using different gears. Fishing is banned from mid-April to mid-May on the operation of mechanized crafts to conserve fishery resources. The traditional crafts using gillnets, seines, and the lines carryout fishing activities throughout the year; however, the fishermen abstain from fishing activity at sea during cyclone warning times. All twenty marine species harvested from the coastal waters of Visakhapatnam occur at different depths ranging from 0 to 2,870 m. The fin fish, *Xiphias gladius* is the largest in size at maturity and it is the only species that occurs commonly throughout the year whereas all other species vary in size at maturity from seven to 250 cm and occur for three to ten months for harvest. Of the twenty species, *Lutjanus argentimaculatus*, *Johnius dussumieri*, *Trichurus lepturus*, *Katsuwonus pelamis*, and *Xiphias gladius* spawn throughout the year while all other species spawn seasonally.

Morphometric data were provided for all twenty marine fish species collected from the coastal waters of Visakhapatnam for future use to evaluate the length-weight relationships and their value in understanding stock composition, growth, life span, production, and mortality. Additionally, the morphological characters of three Pomfret species, *Pampus argenteus, Pampus chinensis*, and *Parastromateus niger* are described because they have been chosen for the assessment of protein content and heavy metal concentrations of arsenic, cadmium, mercury, and lead in their muscle and gill portions.

The physico-chemical parameters such as pH, salinity, dissolved oxygen, biological oxygen demand, and temperature were recorded in summer season from the coastal surface waters 500 m away from the Visakhapatnam harbour. The study indicated that pH and salinity values are high, while the values of other parameters are low; this trend is attributed to offshore divergence which dilutes pollution levels. It is found that the harbour area of Visakhapatnam is consistently polluted due to influx of various industrial effluents and domestic sewage; for this reason, the study of these parameters is not needed but it underlined the need to regulate pollutants into the harbour waters to enable the latter to recover back to its previous state with their native stenoecious species and maintain the water chemistry of coastal surface waters for the sustainability of marine fishery resources.

The total protein content in the muscle of Pomfret species, *Pampus argenteus, Pampus chinensis*, and *Parastromateus niger* was analyzed; it was 18.28% in the first species, 16.24% in the second species and 19.58% in the last species. These values have been attributed to the size, age, and food sources available to these species in their habitat. Further studies on the total protein content in individuals of these Pomfret species with different age and size collected from different locations of coastal waters of Visakhapatnam are required to evaluate accurately the potential of these fishes as protein sources depending on their feeding environment.

In fishes, heavy metal bioaccumulation is species-dependent and is related to the bioconcentration capacity of individual species, their habitats, and feeding habits such as carnivore, herbivore, and omnivore. Further, variations of concentrations of heavy metals in different species is also related to body weight and length, gender, age, growing rate, body portions analyzed, and physiological conditions. The type and level of water pollution, chemical form of metal in the water, water temperature, pH value, dissolved oxygen concentration, water transparency are other factors that influence heavy metal concentrations in different fishes. Water temperature plays an important role in the rate of uptake and elimination of heavy metals and causes differences in metal deposition rates in different organs affecting certain physiological processes. In this study, the detected concentration of arsenic in both muscle and gill portions individually or combined in all the three Pomfret species, *Pampus argenteus, P. chinensis*, and *Parastromateus niger* is highly negligible and far below the recommended limit fixed by FSSAI (2011) and hence is safe for consumption by humans. The detected concentrations of cadmium and lead in the muscle and gills of the three Pomfret species do not fall within the recommended limits set by all the regulating agencies. Cadmium concentration detected in the muscle and gills of *P. argenteus*, in the gills of *P. chinensis* and *P. niger* is within the permitted limit and in the muscle of *P. chinensis* and *P. niger* slightly exceeded the permitted limit according to EU (2006) and FAO (2003) regulations. But the detected cadmium concentration in both muscle and gills of all the three fish species is beyond the recommended limit according to MAFF and FSSAI (2011). Mercury concentration in the muscle of *P. argenteus* and in the muscle and gills of *P. niger* is within the recommended limit according to EU (2006), FAO/WHO (2011), FAO (2003), MAFF, and FSSAI (2011) while its concentration in the gills of *P. argenteus*, muscle and gills of *P. chinensis* exceeded slightly beyond the permitted limit by all these regulating agencies. Lead concentration detected in the muscle and gills of *P. argenteus, P. chinensis,* and in the muscle of *P. niger* is within the permitted limit according to the regulations of EU (2006), FAO/WHO (2011), FAO (2003), MAFF, and FSSAI (2011). But the lead concentration levels in the gills of *P. niger* slightly exceeded the permitted limit according to EU (2006), FAO/WHO (2011), and FSSAI (2011) prominently exceeded the permitted limit according to FAO (2003) and MAFF. Therefore, the results indicate that consuming these fish species from coastal waters of Visakhapatnam is largely not harmful because the levels of heavy metals analyzed are either below or slightly beyond the permissible limits. However, it is important to state that cadmium levels in the muscle of *P. chinensis* and *P. niger*, and mercury levels in the muscle of *P. chinensis* are causes of concern in the long run because their muscle portion is the main edible part. The people who consume *P. chinensis* and *P. niger* regularly or frequently are more prone to the health risks associated with high levels of cadmium and mercury.

The study suggests that strategies are needed for the conservation and management of marine fishery resources of coastal waters of Andhra Pradesh State. Location-based studies are required to document marine fishery resources, their migration types, feeding habits, their present status according to IUCN criteria, and risk of their exposure to marine pollution during their life cycle. Further, studies on heavy metal contamination in each edible marine fish species are required to alert fish consumers and take appropriate actions to control marine pollution. Finally, regular monitoring of marine resources is essential improve the quality of seafood against contaminants, especially heavy metals to protect the health of fish consumers and for managing the coastal waters in an ecologically sustainable manner.

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