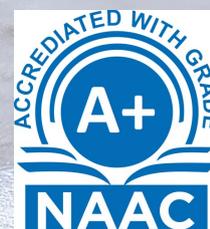
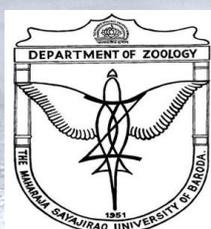


Synopsis of the Thesis Entitled

**Mullet Fish Resources of Coastal Gujarat with Special Reference
to Biological Aspects and Aquaculture Potential of
Mugil cephalus (Linnaeus, 1758)**

Submitted to

THE MAHARAJA SAYAJIRAO UNIVERSITY OF BARODA



For the Degree of
DOCTOR OF PHILOSOPHY
IN
ZOOLOGY
By

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(Registration No. FOS/2197, Date: 06/10/2020)

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July

2023

INTRODUCTION & REVIEW OF LITERATURE:

Oceans and major seas constitute approximately 71% of Earth's surface, with a coastline of approximately 1.6 million km. Coastal and marine ecosystems occur in 123 countries which include estuaries, lagoons, sand dunes, near shore coastal areas and open marine areas. The Indian Ocean covers approximately 29% of total ocean area ranks 3rd largest ocean (Venkatraman & Raghunathan, 2015). India – a mega biodiversity nation is an integral and largest part of the central Indian ocean region along with other countries Bangladesh, Indonesia, Maldives, Malaysia, Myanmar, Thailand and Sri Lanka (Gopi & Mishra, 2015). India is surrounded by three distinct marine ecosystem zones of the central Indian ocean marine region: the Arabian Sea on West, the Bay of Bengal on East and the Indian Ocean south of India (Gopi & Mishra, 2015). In terms of coastal habitat, India has a coastline of approximately 8000 km including Andaman-Nicobar and Lakshadweep Islands (Venkatraman & Raghunathan, 2015).

Coastline area forms unique habitats such as estuaries, lagoons, mangroves, backwaters, salt marshes, rocky coasts, sandy stretches and coral reefs ecosystems. Among which estuarine zone forms a unique ecosystem and makes a transition zone between the marine and freshwater ecosystem (Sarkar et al., 2012). In India, 14 major and 228 minor estuaries are present beside coastal lagoons and backwaters draining approximately 2000 km² hinterland (Sarkar et al., 2012; Venkatraman & Raghunathan, 2015). Estuarine ecosystem is one of the most productive ecosystems of the world consists following properties: abundant number of autotrophs, high oxygen content due to tidal current, influx of inorganic and organic detritus from rivers and coastal wetlands and complex food chain which makes rapid conversion and regeneration of nutrients (Acharya et al., 2019). Estuary is an intermediate zone between marine and fresh waters which faces dramatic changes in temperature, salinity and turbidity, and are regarded as one of the most dynamic aquatic habitats for fishes. Estuaries play an important role in ichthyofaunal life cycles. Estuary is a home to many fish species as well as important breeding and nursery ground for certain fishes as it provides nutrient rich food and protection (Whitfield, 1994).

An estuary is a partially enclosed coastal body of water which is either permanently or periodically open to the sea and within which there is a measurable variation of salinity due to the mixture of sea water with freshwater derived from land drainage (Day, 1981). The ichthyofauna of many tropical estuaries are onto the shallow coastal waters and there is only a gradual change to marine conditions. Thus, Blaber (1997a) expanded the definition to include shallow coastal waters that are adjoining with estuaries and have similar reduced salinities. He

also classified estuaries in four broad categories - open estuary, estuarine coastal waters, blind estuary and coastal lake. In estuarine ecosystem diversity of the species may be less but the present populations are highly abundant than adjacent aquatic environments (Chang & Iizuka, 2012). In most part of the tropical countries, estuaries play an important role in terms of economy and major source of fish to local people.

Globally, ichthyofaunal diversity comprises approximately half of the total members of the subphylum Vertebrata with 35, 588 valid fish species (Fricke et al., 2020). Recent findings have increased number of valid fish species in India with an estimation of 3231 species of freshwater, brackish water and marine species (Gopi & Mishra, 2015). Out of the total fish diversity, marine water consists 2443 species, freshwater consists 675 species (Gopi & Mishra, 2015) and brackish water comprises approximately 113 species (Sarkar et al., 2012).

The Mugilidae Jarocki, 1822 commonly known as grey mullets, are one of the most ubiquitous teleost families in coastal waters of the world which belongs to class Actinopterygii, order Mugiliformes (Fricke et al., 2020). Previously, grey mullets were included in order Perciformes but now it is the only representative of Mugiliformes (Nelson, 1984). Mulletts acquire a maximum size of 120 cm standard length, but in usually found in 30 cm standard length; subcylindrical body; head often broad and flattened dorsally (rounded in genera *Agonostomus* and *Joturus*) (Harrison & Howes, 1991). They occur in most temperate, sub-tropical and tropical waters in both hemispheres. Majority of the species are euryhaline, found in coastal marine waters, hypersaline to brackish water lagoons, estuaries and freshwater (González-Castro, 2007), where the sediment is enriched with organic matter (Blaber & Whitefield, 1977b; Odum, 1970; Odum, 1988; Mallo et al., 1993; Cardona et al., 2001). As a family they have an extraordinary adaptability, which has resulted in species that are found mainly in the clear and pristine waters of coral reefs to those that prefer highly turbid estuarine and fresh waters. Some of the species can even inhabit in some of the most polluted waters in the world, e.g., in the harbour at Visakhapatnam in India (Blaber, 2000). Wherever grey mullet occur they often dominate the fish fauna and due to their primarily detritivores feeding occupy a unique position in the food web. In food web, mullets occupy a comparatively low position which makes them comparatively efficient secondary producers of protein. Their food includes particulate organic matter, detritus and benthic microalgae. In Pisces, no other family members rely so much on microphytobenthos, which are major food component of mullet diet. Thus, mullets can make high quality fish protein available to top predators (Whitefield et al., 2012).

In some areas their species diversity may be very high, e.g., in the St. Lucia coastal lake system in South-East Africa at least 10 species are sympatric (Blaber 1976).

Euryhaline ecosystem has fluctuating environmental conditions, in which such fishes like mullets are flourishing. These parameters effect on the growth and breeding cycles of the individual species. Mulletts spawn in sea water while fries and juveniles move towards the coastal waters and enter estuarine zones. This is a feeding ground of most of the mullets and gets protection from predation (Crosetti & Blaber, 2016). Environmental parameters such as pH, temperature, salinity, dissolved oxygen etc. play an important role in the growth and development of the estuarine fishes. The growth of euryhaline species may affect by salinity because the energy which requires for osmoregulation is not available for growth (Brett, 1979; Wootton, 1990). Mulletts are highly euryhaline fishes and adapted to a wide range of salinities, from 0 to 113 (Thomson, 1966; Kutty, 1980; Whitfield, 1996). Due to their euryhalinity nature, mullets can be stocked in brackish water lagoons and coastal wetlands to improve fish yield (Ravagnan, 1992). They can be raised in commercial freshwater fish-ponds (Thomson, 1966; Pillay, 1993) and introduced into fresh water lakes and reservoirs to improve water quality (Leventer, 1981) and create new fisheries (Thomson, 1966; Ben Tuvia et al., 1992).

The growth and condition of the fish mainly measured by isometric and allometric type of growth. In isometric growth, fish length and weight grow in same proportions while in case of allometric, it can be positive or negative allometric growth (Le Cren, 1951). Length-weight relationship and condition factor of the fishes from different zones of coastal waters give an idea about the quality of the fish and condition which eventually beneficial for the fishery and aquaculture sector. It helps in comparison among species or among populations of the same species from different habitats and/or regions (Mendes et al., 2004). Renjini & Bijoy (2011) reported b value of gold spot mullet *Liza parsia* was 3.1545 for male and 3.0094 for female and 3.1938 for combined group from the Champakkara region of Cochin estuary and growth of the species was found positive allometric. Rao et al., (2005) studied length-weight relationship of *Liza parsia* in relation to industrial pollution and found b value as 2.4986 for polluted waters and 2.5210 in non-polluted waters of Visakhapatnam. Moorthy et al. (2003) obtained length weight relationship of *Velamugil seheli* from Mangalore which was $W = 0.0372 L^{2.6294}$ for male and $W = 0.0502 L^{2.5283}$ for female with negative allometric form of growth.

Similarly, to check the spawning season of the mullet gonadosomatic index is used. The term was proposed by Meien (1927) and since then there have been ample studies in which GSI has been used as an indicator of gonad development. Gonadosomatic index provides the

information of gonadal development changes of a species in every month which can be useful for the management of fishery and aquaculture sector. Hepatosomatic index is performed with relation to gonadal development. As the size of gonad increases the size of the liver decreases. The hepatosomatic index is significantly related to the gonadosomatic index, suggesting that vitellogenesis utilizes hepatic energy during reproduction (Albieri & Araújo, 2010).

Fish being a food recognized as a valuable source of high quality of protein in human food consumption. Mullet is commonly preferred and consumed by all the economic group as they are considered as excellent fish meal and have good market demand. The diverse feeding habit, dependence on particulate organic matter, detritus and non-predacious nature makes mullet highly nutritive fish as they are efficient converters of natural food compare to other species (Whitfield et al., 2012). The high protein levels, with good digestibility and low-fat content are advantages of Seafood (Pigott & Tucker, 1990). Proximate composition generally means percentage composition of basic constituents such as water, protein, lipids, carbohydrate and minerals which are considered as macronutrients (Kumaran et al., 2012). Tulgar & Berik (2012) performed season wise proximate content analysis of red mullet in Turkey. They found average composition of macronutrients in which water (75.25%), protein (17.75%), lipid (5.25%), ash (1.19%) and carbohydrates (1.01%). Kumaran et al., 2012 performed the proximate content analysis of *Mugil cephalus* from Tamil Nadu. He found that the moisture, carbohydrate, lipid, protein and crude ash content of the *M. cephalus* was 75.27%, 1.2%, 2.42%, 17.56% and 1.15%, respectively. These findings suggest that mullets contain high quality and quantity of proteins.

Not surprisingly these fish are economically important in most regions, particularly the worldwide species *Mugil cephalus*, which forms the basis of significant commercial fisheries in developed parts of the world such as Australia and the U.S.A., as well as vital artisanal and subsistence fisheries in developing countries. Mulletts are also cultured in many regions of the world, both in extensive systems, such as the more or less confined coastal lagoon areas in the Mediterranean region, and in semi-intensive and intensive systems, often in polyculture with other species, though culture is still based on the collection of wild fries, as no induced spawning is practiced at a commercial level. Egypt is by far the greatest producer of cultured grey mullets, with 84% of the world mullet aquaculture production (138,143 tonnes in 2013, FAO 2015). FAO (2015) report mentioned that the total production of Mugilidae was reached to 7 lakh tonnes in 2013 which includes 80.2% from capture fishery and 19.8% from aquaculture. Asia ranks first in mullet production with 70% of world's total production. In India, mullets contribute one of the major brackish water fisheries with 18 species reported

from seven genera (Joshi et al., 2018). Of these, 8 species contribute to the commercial catches. They are *Mugil cephalus*, *Mugil cunnesius*, *Liza macrolepis*, *Liza parsia*, *Liza tade*, *Ellochelon vaigiensis*, *Valamugil seheli* and *Rhinomugil corsula* (Luther, 1973). The principal regions supporting mullet fishery are the estuaries of the rivers Ganga, Mahanadi, Godavari, Krishna and Cauvery and the brackish water lakes of Chilka and Pulicat on the east coast, the estuaries of the Narmada, Tapti, the Gulf of Kutch and the backwaters of Kerala notably the Vembanad Lake, the Kayamkulam Lake and the Ashtamudi Lake on the west coast (Luther, 1973).

Gujarat being a state of India having largest coastline with diverse coastal habitats. At present, Gujarat is the largest fish producing state in India (Handbook on Fisheries Statistics, India 2018). Gulf of Khambhat, Gulf of Kachchh and Saurashtra peninsula have many major and minor fish landing centres. Out of total fishery resource of the Gujarat, total mullet production was reported approximately 8000 metric tonnes in 2000 which includes marine and inland production (FAO, 2000). This is quite less compared to the other coastal states Andhra Pradesh, Tamil Nadu and West-Bengal. In Gujarat, many estuarine forming rivers, large coastal wetlands and lagoons are present where aquaculture of mullets can be proposed. At present, human consumption increases every day, thus need of quality food also increases. Mullet fish can be a potential fishmeal which can compensate the demand of nutrient rich food. In Gujarat, very few studies have been carried out on diversity (Rao & Shashtri, 2005; Saravanakumar et al., 2009; Gohil & Mankodi, 2013; Brahmane et al., 2014; Parmar et al., 2015; Bhakta et al., 2017; Raval et al., 2017; Sarma & Mankodi 2017; Joshi et al., 2018; Bhakta, 2019; Bhatt & Mankodi, 2020) and biology of mullets. Hence, there is a need of detail investigation on diversity and biology of mullets in the state to find out possible management measures in capture fisheries as well as to explore aquaculture potential. The present study will be useful in the context of diversity status, biology and aquaculture management and potential development in Gujarat state, India.

ORIGIN OF THE STUDY:

Gujarat state is having longest coastline among Indian states with approximately 1600 km, which constitutes about 21% of the Indian coastline. The coastal regions of the state are divided into three major regions viz. Gulf of Kachchh, Saurashtra coast and Gulf of Khambhat. These regions support diverse type of coastal habitats such as estuaries, coastal wetlands, coastal lagoons, coral reefs, and sandy/muddy/rocky shores which hold rich diversity of organisms. Many researchers have worked on the diversity and biology of the ichthyofauna of the Gujarat coast. Among all the ichthyofauna found in Gujarat coast, very few studies carried

out on the diversity of family Mugilidae. There is no such study reported on the biology of family Mugilidae from Gujarat Coast. Mulletts are highly consumed fishes in coastal regions and having high nutritive values. Mulletts have specialized kind of habitat preference migrating sea waters to estuarine area and some may reach to freshwater areas. This euryhaline nature of mulletts and detritus feeding habit make them protein rich food for locals. *Mugil cephalus* is showing highest range of euryhaline nature among all mulletts. At present, brackish water aquaculture is highly developing sector and Gujarat state has a potential to develop this sector. Thus, present study has been designed to fill the lacuna of the knowledge about the diversity of mulletts and biology of *M. cephalus*.

OBJECTIVES:

- 1) Species Diversity and Distribution of Mulletts - [Family: Mugilidae Jarocki, 1822] from Coastal Waters of Gujarat, India.**
 - a. Taxonomy based on Morphology, Morphometry and Meristic analysis.
 - b. Molecular taxonomy and Phylogenetics.
 - c. Present Distribution status of Mulletts in Gujarat.
- 2) Environmental (Water Parameters) and biological aspects of *Mugil cephalus* (Linnaeus 1758) from selected Coastal and Estuarine Zone of Gujarat.**
 - a. Water parameters analysis of selected stations of Marine and Estuarine Zones of Gujarat.
 - b. Length-Weight Relationship and Fulton's Condition Factor of *Mugil cephalus* (Linnaeus, 1758).
 - c. Gonadosomatic Index and Hepatosomatic Index of *Mugil cephalus* (Linnaeus, 1758).
- 3) Status and Potential assessment of Mullet culture in Gujarat, India.**
 - a. A proximate analysis - Moisture, Total Ash, Total Fat, Total Protein and Carbohydrate content of *Mugil cephalus* (Linnaeus, 1758).
 - b. Organoleptic study of *Mugil cephalus* (Linnaeus, 1758).

MATERIALS & METHODS:

STUDY SITES:

To study the species diversity of family Mugilidae Jarocki, 1822, samples were collected from major landing centres of the Gujarat coast. To study the biological aspects and aquaculture potential of *Mugil cephalus* (Linnaeus 1758), two sites were compared viz. Narmada estuary and Diu backwaters (20° 43' 46"N 70° 59' 13"E). *M. cephalus* occupies certain regions when it enters in the estuarine zone which forms a microhabitat. Thus, In Narmada estuary three stations were selected namely Bharuch (22O25'78''N, 73O53'91''E), Bhadbhut (21O40'70''N, 72O50'69''E), and Ambetha (21O40'81''N, 72O35'70''E) to compare the variations in growth and nutrient profile according to their microhabitat

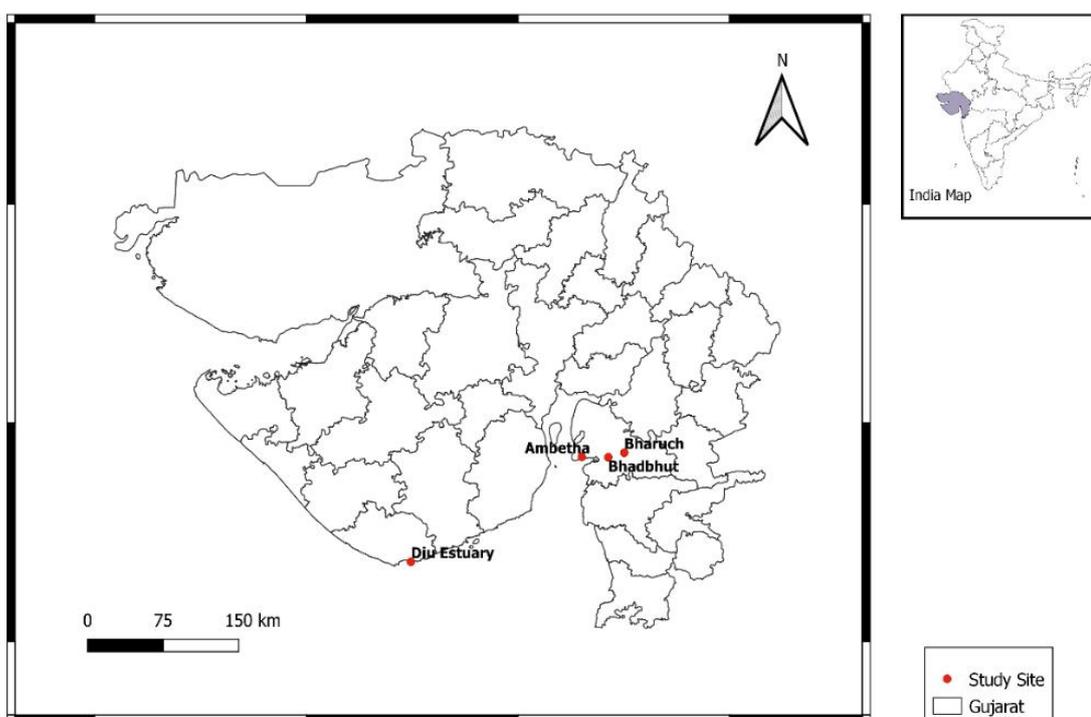


Figure 1: Gujarat State, India: Study sites: (01) Narmada estuary: Bharuch, Bhadbhut and Ambetha (02) Diu lagoon.

METHODOLOGY:

Methodology will be mainly categorised under three parts.

01) To study the diversity and distribution of Family Mugilidae Jarocki, 1822

- To study the existing species diversity of mullets, fresh samples were collected from the major estuarine area and fish landing centres of Gujarat Coast over a period of two years *i.e.*, from December 2020 to November 2022.

1a. To study Morphology, Morphometry and Meristic characters of mullets.

- On field: Visible characters such as presence or absence of adipose eyelid and colouration were noted down and photographs of the specimen were taken.
- Further, specimens were preserved in ice-box and transported to the laboratory at Department of Zoology, Faculty of Science, The Maharaja Sayajirao University of Baroda, Vadodara for further study.
- In laboratory: Morphological features of specimens were examined with fine precisions.
- Identification conformation of the species was done with help of authenticate available literature (Day, 1888; Thomson, 1997).
- Approximately seventeen morphometric characters were noted down (Thomson, 1997).
- The measurements were taken by using normal centimetre scale, fine pointed divider and forceps to the nearest cm.
- Meristic analysis was carried out by counting number of branchiostegal rays, fins, spines, rays, lateral & transverse scales.

1b. Molecular taxonomy and Phylogeny

- The tissue from the frozen specimens was collected and stored at -20°C till further use.
 - Procedure of DNA extraction was carried out in Freshwater and Marine Biology laboratory, Department of Zoology, The Maharaja Sayajirao University of Baroda, Vadodara as facility of PCR amplifier is available.
 - DNA pellet was obtained using standard protocol and mitochondrial gene Cytochrome Oxidase I (COI) was amplified from extracted DNA.
 - After extraction of DNA, quantification of DNA was carried out by calculating the ratio of absorbance at 260nm and 280nm.
 - Agarose Gel Electrophoresis was performed.
- **DNA amplification:**
- Polymerase Chain Reaction: PCR was carried out using 2X final concentration of One Taq® Standard Buffer and, template DNA. The reaction was carried out in Thermal cycler using forward and reverse primers.

- Obtained PCR products were further sent to Gujarat Biotechnology Research Centre (GBRC) or any other Institute for Sanger sequencing.
- Sequence analysis was done using sequencing analysis version 5.4 (Applied Biosystems) and BioEdit, biological sequence alignment editor (Ibis Biosciences) (Hall, 2013).
- Consensus sequences generated after aligning gene sequences from forward and reverse primers. These sequences were subjected to Sequence match analysis using Basic Local Alignment Search Tool (BLAST) on NCBI (Altschul et al., 1990; Lobo, 2008).
- Phylogenetic tree will be constructed using MEGA-10 software (Hall, 2013; Kumar et al., 2016).

1c. Distribution status of mullets:

- Present data on distribution of mullets in Gujarat was prepared using available literature and field visits.

02) Environmental and Biological aspects of *Mugil cephalus* (Linnaeus 1758).

(2A) Environmental (Water) parameters such as pH, temperature, salinity, dissolved oxygen and total dissolved solids of the selected stations were obtained using standard equipment.

➤ The measurements were taken in triplicate to validate empirical data or the observed results.

(i) pH:

The pH of the selected study sites was measured using Aquasol Digital – Handheld Ph Meter (AM-PH-01) for the period of two years.

(ii) Temperature:

The temperature of the selected study sites was measured using digital thermometer (MEXTECH – ST9264).

(iii) Salinity:

The salinity of the selected study sites was measured using Erma Handheld Portable Refractometer (Brix 0-100 ‰ Salinity).

(iv) TDS:

The Total Dissolved Solids (TDS) was measured using Aquasol Digital – Handheld TDS Meter (AM-TDS-01; 0 to 19990 PPT).

(v) Dissolved Oxygen: Winkler method was used to determine the DO.

(2B) Length-Weight Relationship & Condition factor: *Mugil cephalus* (Linnaeus, 1758).

- The specimen collection of *Mugil cephalus* was carried out based on the lunar cycle for 24 months to cover all the seasons.

- Total length nearest to 0.1 mm and total body weight (BW) nearest to 0.1 g were measured.
- The LWR was measured using equation $W = aL^b$, where 'W' and 'L' represent weight and length respectively (Le Cren, 1951).
- The values of 'a' and 'b' were calculated using logarithmic form of the LWR equation as follows: $\text{Log}(BW) = \text{Log}(a) + b \text{Log}(TL)$ (Le Cren, 1951).
- Fulton's condition factor (K) was measured to evaluate the condition of the species at given month using the following equation:
 - $K = 100 \times (BW/TL^3)$, where BW = total body weight in nearest to 0.1 g and TL = total length in nearest to 0.1 cm (Fulton, 1904).

(2c) Gonadosomatic Index and Hepatosomatic Index of *Mugil cephalus* (Linnaeus, 1758).

- The mean gonadosomatic index (GSI) of specimens was calculated for each month using following equation:
 - $GSI = (BW-GW/BW) \times 100$, where GW represents gonad weight and BW indicates total weight (Render et al., 1995).
- The mean hepatosomatic index (HIS) of specimens was calculated for each month using following equation:
 - $HIS = (BW-LW/BW) \times 100$, where LW represents liver weight and BW indicates total weight (Albieri & Araújo, 2010).

(03) Status and Potential assessment of Mullet culture in Gujarat, India.

(3a) Moisture, Total Ash, Total Lipid, Total Protein and Carbohydrate content of *Mugil cephalus* (Linnaeus, 1758).

Moisture Content Analysis:

Oven drying method: AOAC, 1995

- Take 5g of tissue
- Put it onto Petri dish.
- Transfer to oven and set temperature – 100°C for 3 hours.
- Calculate: Moisture content = $\frac{\text{Weight of Wet sample} - \text{Weight of dried sample}}{\text{Weight of wet sample}} \times 100$

Determination of Total Ash: AOAC, 1995

- Principle involved is that when a known weight of fish is ignited to ash, the weight of ash thus obtained is expressed in terms of percentage.

$$\text{Calculation: Ash content (\%)} = (Z - X / Y - X) \times 100$$

Weight of empty crucible = X g, Weight of crucible + sample = Y g, After complete ashing,
Weight of crucible + ash = Z g

Carbohydrate Analysis by Anthrone Method:

The carbohydrate content in the tissue is analysed by anthrone method (Hedge and Hofreiter, 1962). Glucose is used as standard.

Lipid Estimation Method – Folch et al, 1957

The lipid content in the tissue is analysed by chloroform-methanol method (Folch et al, 1957).

Protein Estimation – Bradford Assay

The protein content in the tissue is analysed by Coomassie Brilliant Blue G-250 method (Bradford Assay).

(3b) Organoleptic study of *Mugil cephalus* (Linnaeus, 1758).

- According to Klein & Bardy (1984), post mortality changes such as aroma (freshness), colour, texture and acceptability can be evaluated by scoring.
- The scale can be given from 1 to 10 as the following: 9-8 very good, 7-6 good, 5-4 fair and 3-1 poor.

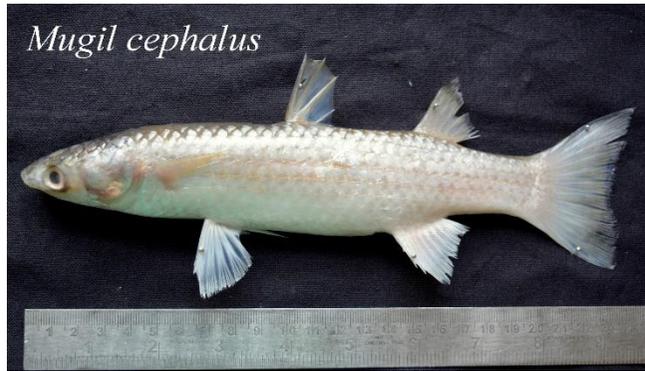
RESULTS:

1. Diversity and Distribution of Family Mugilidae Jarocki, 1822:

A total of six species has been recorded during the study period from the various fish landing centres of Gujarat coast (Figure 2). All the species are distributed throughout the coast of Gujarat except *Minimugil cascasia* (Hamilton 1822). *Minimugil cascasia* (Hamilton 1822) was found from the freshwater habitat of Mahi and Tapi River. It is showing the Potamodromous type of life cycle.

Table 1. Diversity of mullet fishes from Gujarat coast.

Sr. No.	Name of the species recorded
1	<i>Mugil cephalus</i> Linnaeus, 1758
2	<i>Planiliza planiceps</i> (Valenciennes, 1836)
3	<i>Rhinomugil corsula</i> (Hamilton, 1822)
4	<i>Planiliza parsia</i> (Hamilton, 1822)
5	<i>Crenimugil seheli</i> (Forsskål, 1775)
6	<i>Minimugil cascasia</i> (Hamilton 1822)



Mugil cephalus Linnaeus, 1758



Planiliza planiceps (Valenciennes, 1836)



Rhinomugil corsula (Hamilton, 1822)



Planiliza parsia (Hamilton, 1822)



Crenimugil seheli (Forsskål, 1775)

Figure 2. Illustrative photographs of the mullets from family Mugilidae recorded from the coastal waters of Gujarat, India.

2a. Environmental Parameters (Water Parameters):

pH: At Diu, monthly variation of pH shows the range between 8-9 for both the consecutive years i.e., December-2020 to November-2021 and December-2021 to November-2022. The results show the high alkaline nature in winter (Nov-Feb). Whereas, the pH slightly decreases in summer (Mar-Jun) and monsoon (Jul-Oct). At Bharuch, pH ranged between 8.1-9.4. There is sharp decline in pH post winter and again rises during monsoon. It may be because of very less influx of freshwater from upstream during summer. At Bhadbhut, pH ranges between 8.2-9.0. At Ambetha, pH ranges between 7.8-8.9. It shows comparatively low pH from Bharuch and Bhadbhut. It may be because of the discharge of the influent water in estuarine area of the Narmada river (Figure 3).

Temperature: Monthly variation in temperature revealed that the temperature was less during winter season (22°C-27°C) followed by monsoon (27°C-30°C) and summer (29°C-34°C) at Diu. The results were obtained from the sites of Narmada River (Bharuch, Bhadbhut and Ambetha) shows higher temperature during summer compare to Diu lagoon (Figure 4).

Salinity: At Diu, salinity ranged between 36 to 42 ppt which increases during summer and decreases during monsoon and winter respectively. At Bharuch, salinity ranged between 7 to 21 ppt. Bharuch is a starting point of the estuarine area and receives fresh water from the upstream. Therefore, it shows variation in salinity. Also, the variation may observe due to the tidal fluctuations and decrease in freshwater influx during summer. At Bhadbhut, salinity was recorded between 10-26 ppt. Whereas at Ambetha, it was recorded between 34-39 ppt as it is the mouth of the Narmada River (Figure 5).

Dissolved Oxygen: The data revealed that the dissolved oxygen ranged between 7.5-8.4 mg/l at Diu. It decreases during the peak summer at all the study sites. At Bharuch, it ranges between 4.5-5.7 mg/l. At Bhadbhut, it was recorded between 5.5-6.6 mg/l. It was recorded 6.2-7.2 mg/l from Ambetha (Figure 6).

Total Dissolved Solids: The data of total dissolved solids revealed high concentration during monsoon followed by summer and winter (Figure). It ranges between 36000-70000 mg/l, 10000-11000 mg/l, 2000-16000 mg/l and 44000-70000 mg/l at Diu, Bharuch, Bhadbhut and Ambetha respectively (Figure 7).

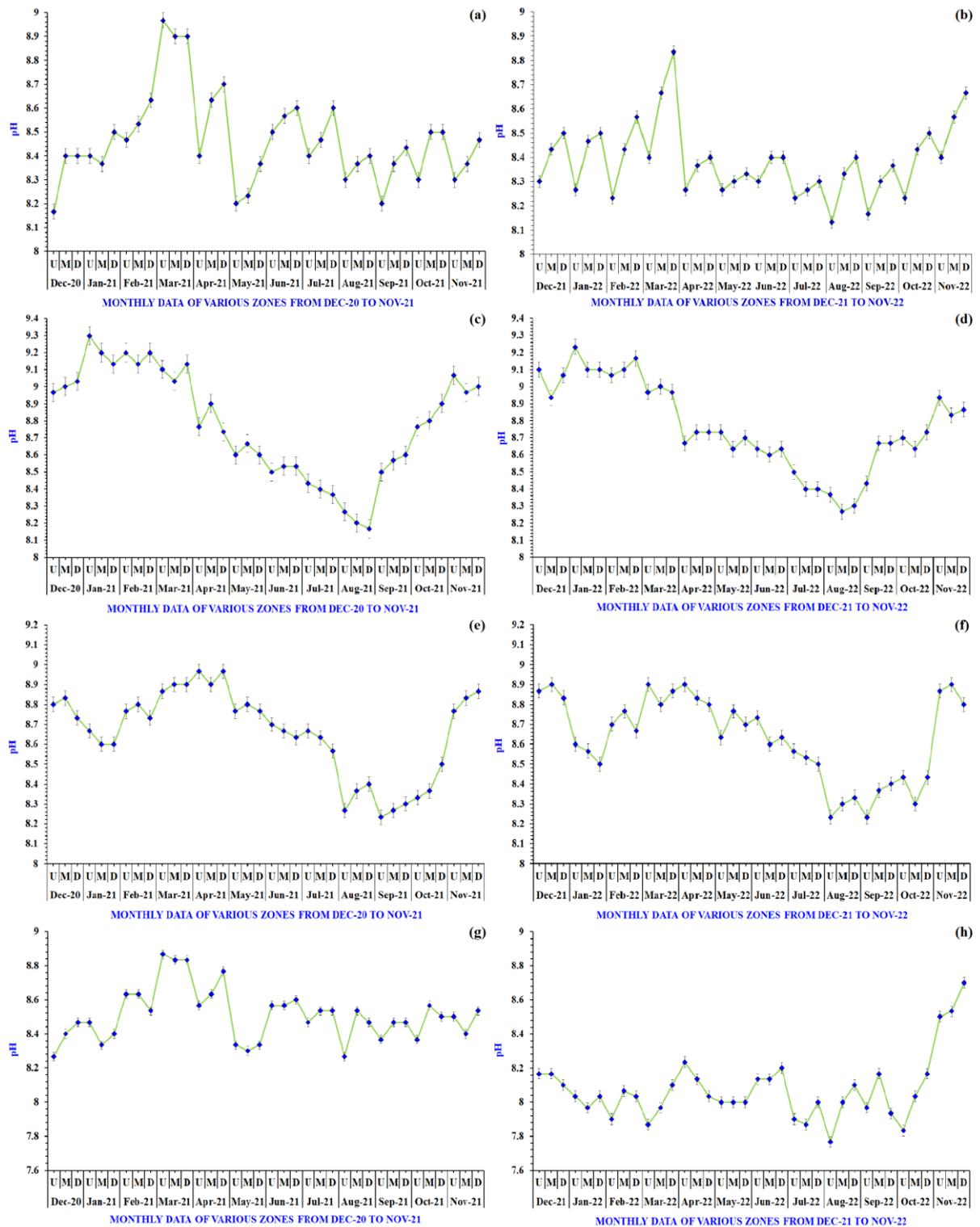


Figure 3: Monthly variation in pH from December 2020 to November 2022 (a) Diu – Dec 2020 to Nov 2021, (b) Diu – Dec 2021 to Nov 2022, (c) Bharuch - Dec 2020 to Nov 2021, (d) Bharuch - Dec 2021 to Nov 2022, (e) Bhadbhut - Dec 2020 to Nov 2021, (f) Bhadbhut - Dec 2021 to Nov 2022, (g) Ambetha - Dec 2020 to Nov 2021, (h) Ambetha - Dec 2021 to Nov 2022.

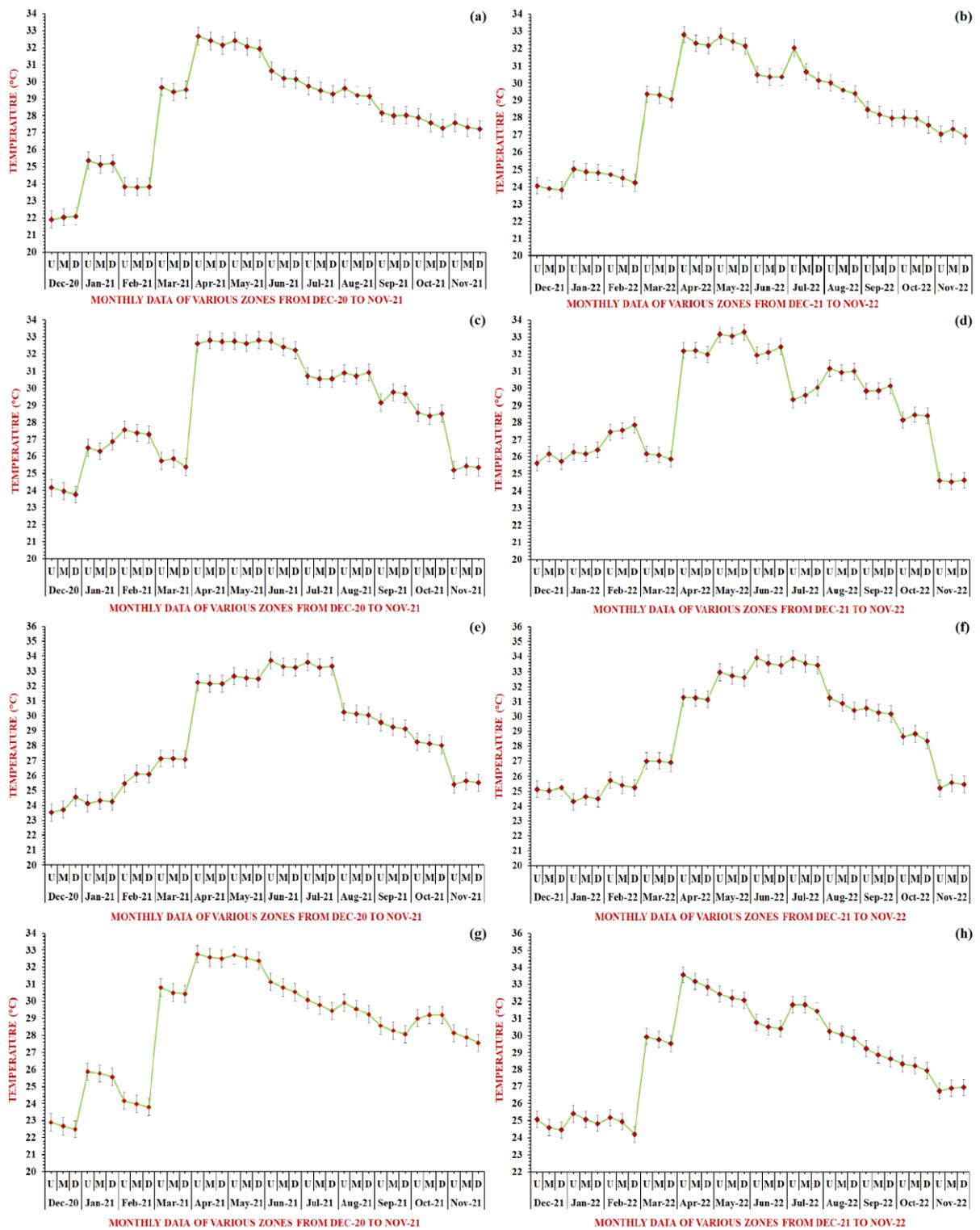


Figure 4: Monthly variation in Temperature from December 2020 to November 2022 (a) Diu – Dec 2020 to Nov 2021, (b) Diu – Dec 2021 to Nov 2022, (c) Bharuch - Dec 2020 to Nov 2021, (d) Bharuch - Dec 2021 to Nov 2022, (e) Bhadbhut - Dec 2020 to Nov 2021, (f) Bhadbhut - Dec 2021 to Nov 2022, (g) Ambetha - Dec 2020 to Nov 2021, (h) Ambetha - Dec 2021 to Nov 2022.

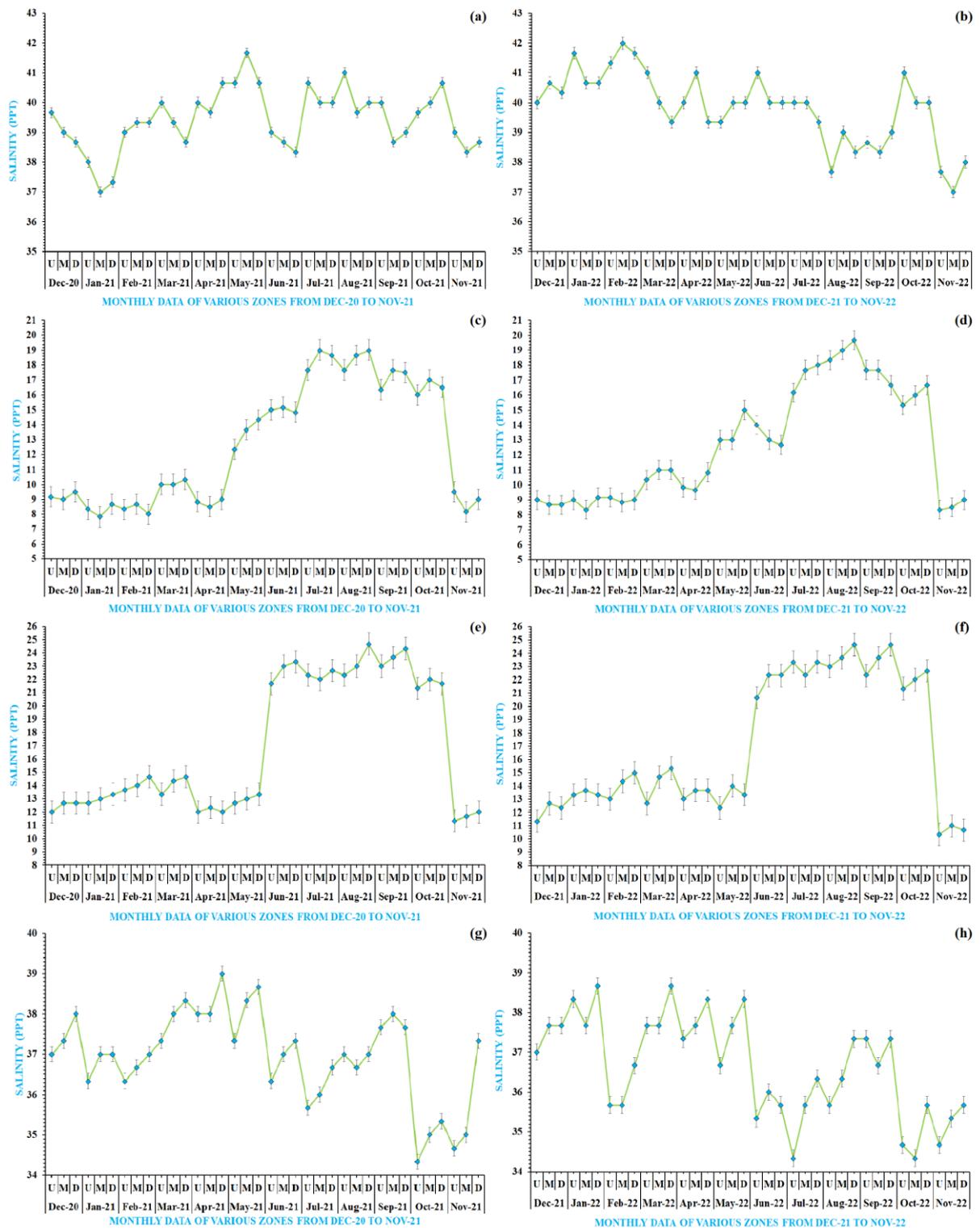


Figure 5: Monthly variation in Salinity from December 2020 to November 2022 (a) Diu – Dec 2020 to Nov 2021, (b) Diu – Dec 2021 to Nov 2022, (c) Bharuch - Dec 2020 to Nov 2021, (d) Bharuch - Dec 2021 to Nov 2022, (e) Bhadbhut - Dec 2020 to Nov 2021, (f) Bhadbhut - Dec 2021 to Nov 2022, (g) Ambetha - Dec 2020 to Nov 2021, (h) Ambetha - Dec 2021 to Nov 2022.

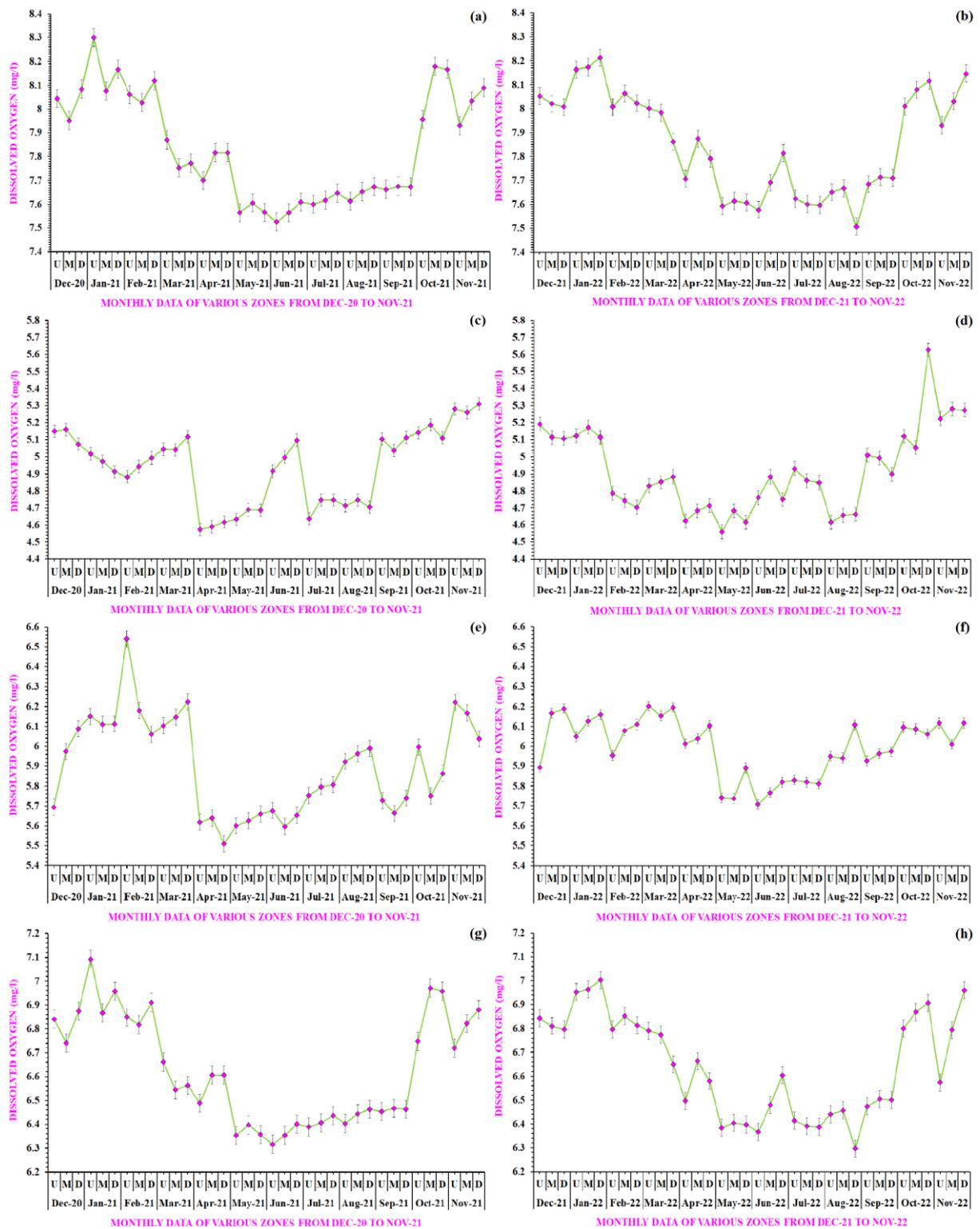


Figure 6: Monthly variation in Dissolved Oxygen from December 2020 to November 2022 (a) Diu – Dec 2020 to Nov 2021, (b) Diu – Dec 2021 to Nov 2022, (c) Bharuch - Dec 2020 to Nov 2021, (d) Bharuch - Dec 2021 to Nov 2022, (e) Bhadbhut - Dec 2020 to Nov 2021, (f) Bhadbhut - Dec 2021 to Nov 2022, (g) Ambetha - Dec 2020 to Nov 2021, (h) Ambetha - Dec 2021 to Nov 2022.

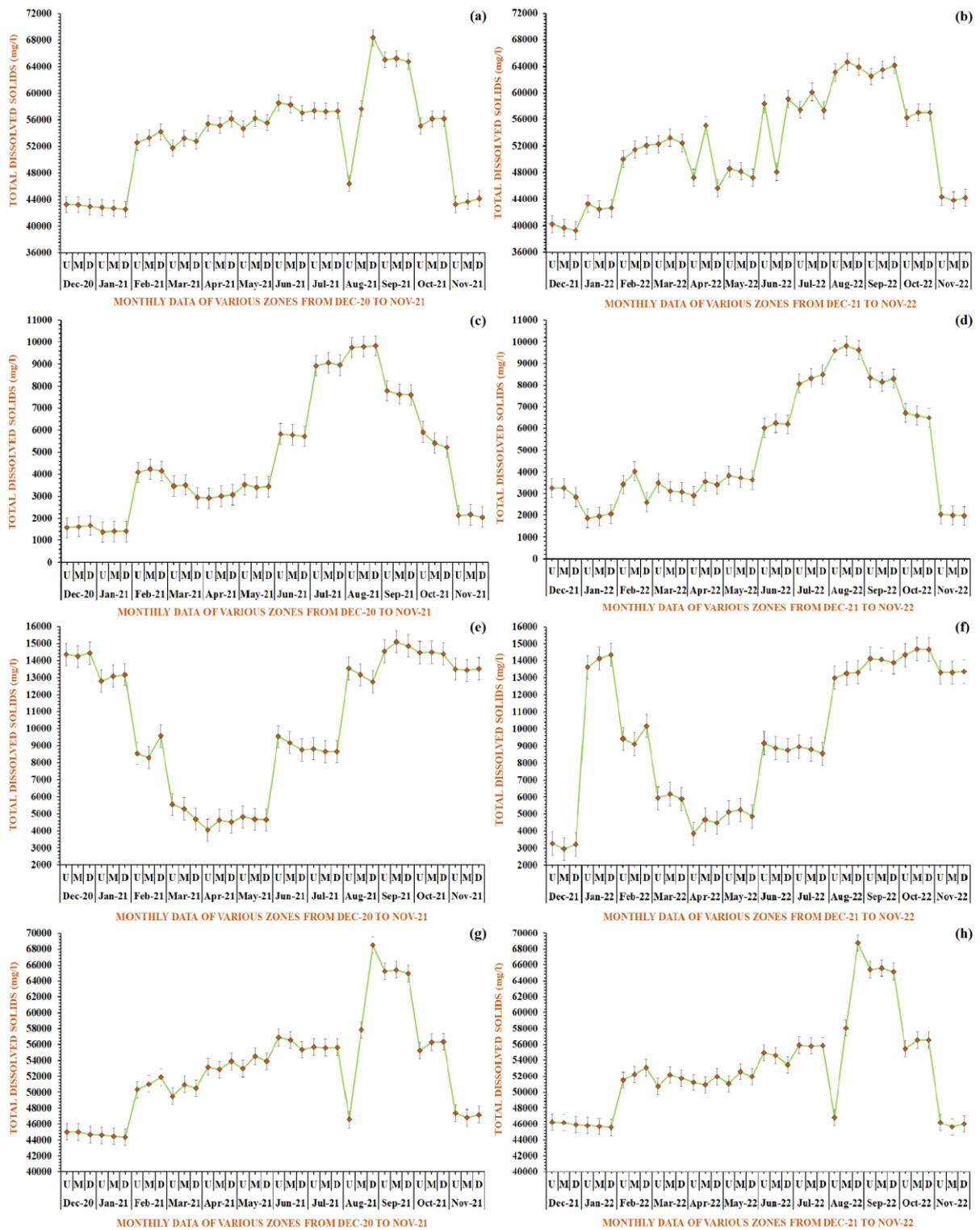


Figure 7: Monthly variation in Total Dissolved Solids from December 2020 to November 2022 (a) Diu – Dec 2020 to Nov 2021, (b) Diu – Dec 2021 to Nov 2022, (c) Bharuch - Dec 2020 to Nov 2021, (d) Bharuch - Dec 2021 to Nov 2022, (e) Bhadbhut - Dec 2020 to Nov 2021, (f) Bhadbhut - Dec 2021 to Nov 2022, (g) Ambetha - Dec 2020 to Nov 2021, (h) Ambetha - Dec 2021 to Nov 2022.

Biological aspects of *Mugil cephalus* (Linnaeus 1758) from selected Coastal and Estuarine Zone of Gujarat:

2b. Length-Weight Relationship:

Table 2. The data represents the Length-Weight Relationship of *M. cephalus* from the Diu lagoon and Narmada estuary.

Study Site	Year	Sex	N	Total Length (cm)		Total Weight (g)		Regression Parameters					Growth (t-test)	P-value
				Min	Max	Min	Max	"a"	95% CI of "a"	"b"	95% CI of "b"	R ²		
Diu	Dec-20 to Nov-21	♂	120	10	23.8	10.76	108.26	0.166	0.147-0.187	2.817	2.717-2.918	0.963	b<3	HS
		♀	120	12.5	29.4	21.37	251.73	0.18	0.157-0.207	2.772	2.667-2.878	0.958	b<3	HS
	Dec-21 to Nov-22	♂	120	11	24	12.76	112.16	0.176	0.153-0.203	2.789	2.673-2.899	0.953	b<3	HS
		♀	120	13	29.2	28.33	258.39	0.191	0.169-0.217	2.753	2.565-2.849	0.964	b<3	HS
Bharuch	Dec-20 to Nov-21	♂	120	13.8	24.7	25.64	120.46	0.165	0.096-.0282	2.86	2.436-3.284	0.602	b<3	HS
		♀	120	15.8	26.7	48.46	216.92	0.325	0.256-0.412	2.369	2.190-2.547	0.854	b<3	HS
	Dec-21 to Nov-22	♂	120	13.2	25.4	25.86	128.09	0.192	0.137-0.267	2.733	2.472-2.994	0.784	b<3	HS
		♀	120	15.3	30.2	41.98	243.11	0.294	0.221-0.393	2.425	2.209-2.641	0.807	b<3	HS
Bhadbhut	Dec-20 to Nov-21	♂	120	11.6	26.2	24.66	119.65	0.657	0.450-0.959	2.472	2.146-2.646	0.544	b<3	S
		♀	120	14.5	28.2	39.38	238.9	0.302	0.248-.368	2.411	2.256-2.563	0.892	b<3	HS
	Dec-21 to Nov-22	♂	120	12.6	25.6	29.26	130.27	0.368	0.268-0.504	2.238	1.992-2.483	0.734	b<3	S
		♀	120	13.6	27.3	35.74	233.48	0.254	0.214-0.301	2.549	2.416-2.682	0.924	b<3	HS
Ambetha	Dec-20 to Nov-21	♂	120	10.3	23.9	12.8	106	0.236	0.201-0.277	2.532	2.403-2.662	0.927	b<3	HS
		♀	120	14.6	29.1	38.21	249.72	0.261	0.206-0.331	2.498	2.315-2.681	0.861	b<3	HS
	Dec-21 to Nov-22	♂	120	12.2	24.5	19.11	141.46	0.213	0.168-0.270	2.648	2.458-2.835	0.866	b<3	HS
		♀	120	13.4	29.6	34.45	269.17	0.224	0.195-0.257	2.46	2.353-2.745	0.954	b<3	HS

The results revealed that all the study sites show the negative allometric growth (Table 2). It indicates that the fish is not gaining weight as the length increases. This may be due to the less availability of the food, competition for the food, stress and anthropogenic activities. The population of Diu shows better growth compare to Narmada estuarine area. At Narmada, the Bhadbhut shows comparatively higher negative allometric growth then the Bharuch and Ambetha. Bhadbhut is a major landing centre and this may also be a hurdle in fish growth.

Condition Factor:

The results of Fulton's condition factor revealed that the condition of the population of *M. cephalus* from Diu is better than the Narmada River. The female population shows the fluctuation in the condition throughout the year which indicates the biological changes in their body (Figure 8).

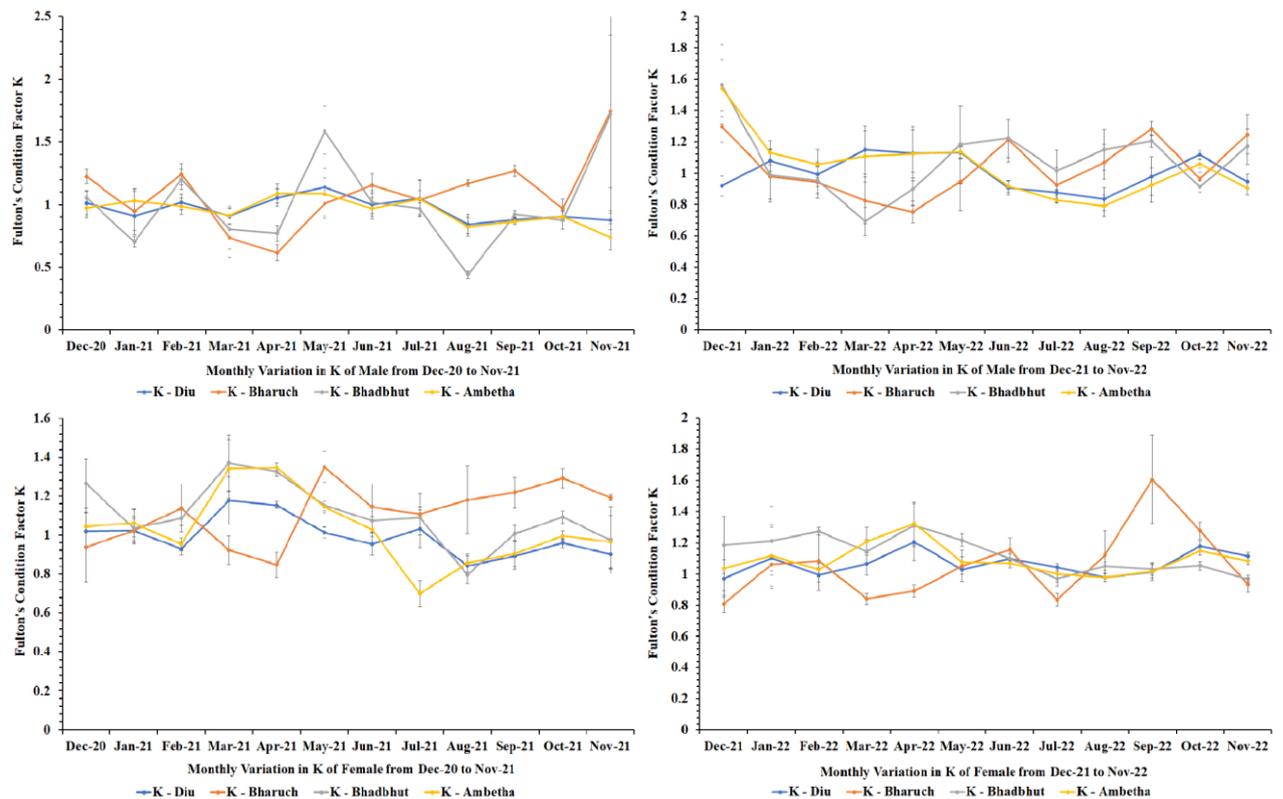


Figure 8: Monthly Variation in Fulton's CF from Diu, Bharuch, Bhadbhut and Ambetha respectively from Dec-2020 to Nov-2022: (a) Male from Dec-20 to Nov-21, (b) Male from Dec-21 to Nov-22, (c) Female from Dec-20 to Nov-21, (d) Female from Dec-21 to Nov-22.

Gonadosomatic Index:

The study of gonadosomatic index revealed the gonadal cycle of *M. cephalus* from the study sites. At Diu, the gonadal cycle in male starts from August and ends in February. Whereas in females, it starts in July and ends in March. The GSI reaches at its peak during November-February. Similar results were obtained from the Narmada River. But there is change in GSI according the sites. At Bharuch, the GSI ranged between 1-7% in males and 2-15% in females. At Bhadbhut, it ranged between 1-10% in males and 2-22% in females. Whereas, it ranged between 1-10% in males and 1-16% in females. Bhadbhut shows the higher GSI in females, this may because of the peak in gonad maturation during Dec-Jan. At Ambetha, it was recorded low because when the population reaches to coastal area, they spent their eggs for fertilization (Figure 9-12).

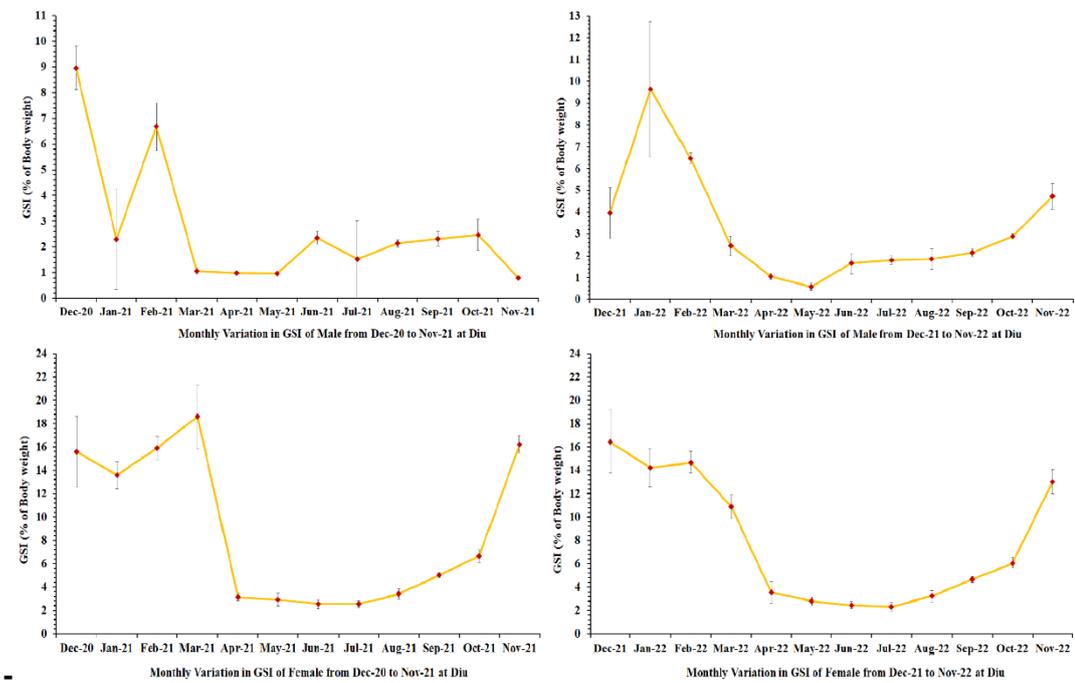


Figure 9: Monthly variation in Gonadosomatic Index from Dec 2020 to Nov 2022 at Diu: (a) Male from Dec 2020 to Nov 2021, (b) Male from Dec 2021 to Nov 2022, (c) Female from Dec 2020 to Nov 2021, (d) Female from Dec 2021 to Nov 2022.

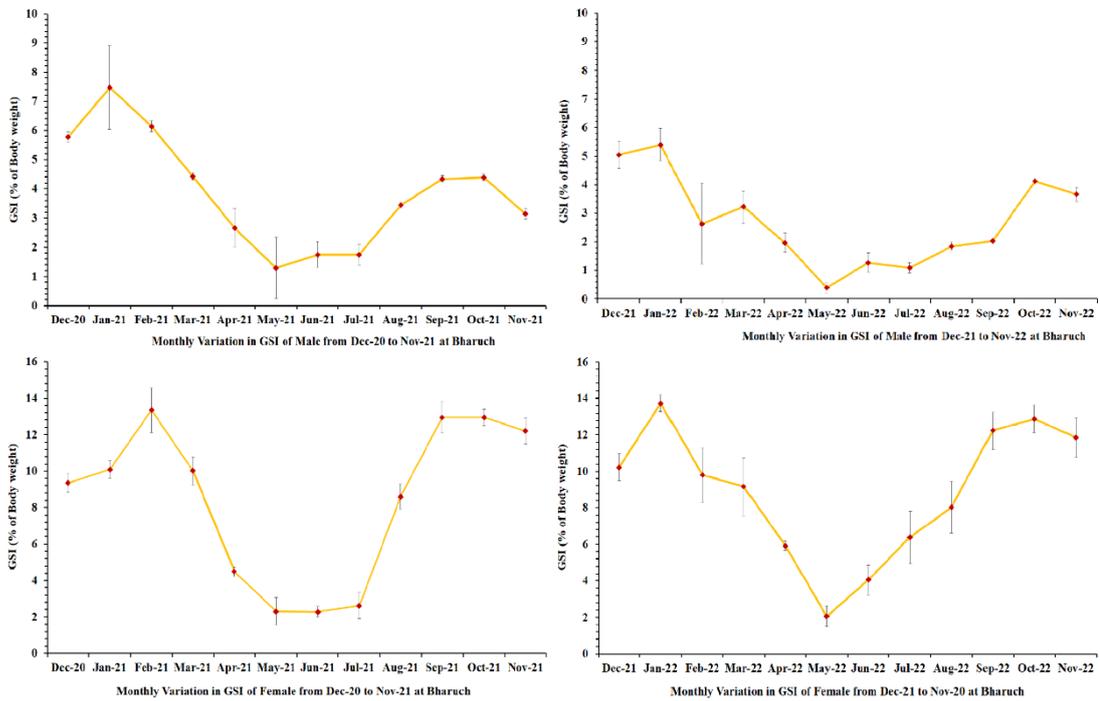


Figure 10: Monthly variation in Gonadosomatic Index (GSI) from December 2020 to November 2022 at Bharuch: (a) Male from Dec 2020 to Nov 2021, (b) Male from Dec 2021 to Nov 2022, (c) Female from Dec 2020 to Nov 2021, (d) Female from Dec 2021 to Nov 2022.

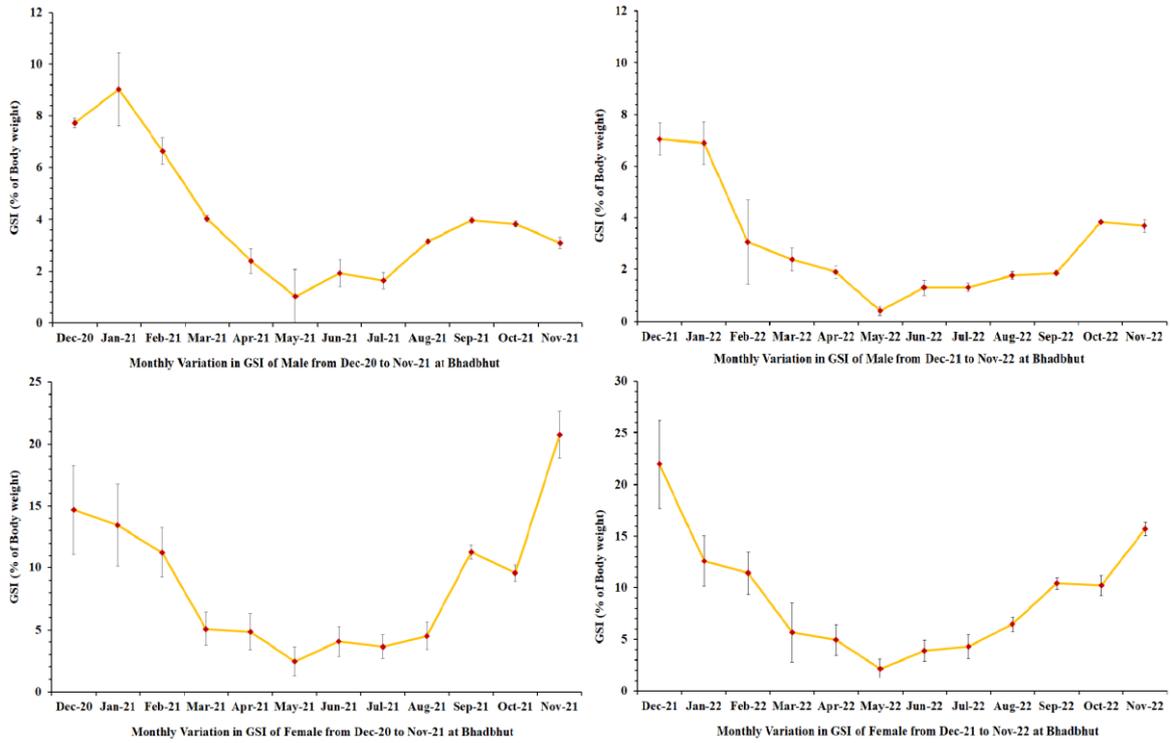


Figure 11: Monthly variation in Gonadosomatic Index (GSI) from December 2020 to November 2022 at Bhadbhut: (a) Male from Dec 2020 to Nov 2021, (b) Male from Dec 2021 to Nov 2022, (c) Female from Dec 2020 to Nov 2021, (d) Female from Dec 2021 to Nov 2022.

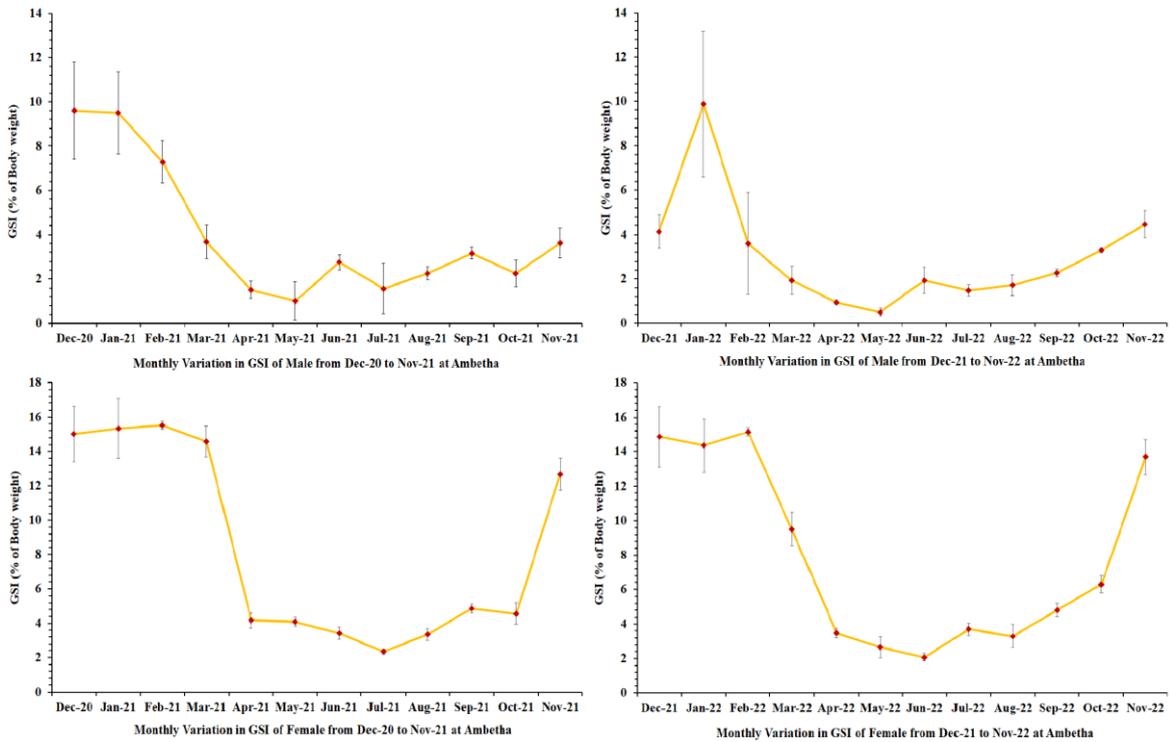


Figure 12: Monthly variation in Gonadosomatic Index (GSI) from Dec 2020 to Nov 2022 at Ambetha: (a) Male from Dec 2020 to Nov 2021, (b) Male from Dec 2021 to Nov 2022, (c) Female from Dec 2020 to Nov 2021, (d) Female from Dec 2021 to Nov 2022.

Hepatosomatic Index:

The data revealed that the hepatosomatic index of all the study sites was lower during the gonadal maturation period. Which clearly indicates that the hepatosomatic index is significantly related to the gonadosomatic index and during vitellogenesis it utilizes hepatic energy for reproduction (Albieri & Araújo, 2010) (Figure 13-16).

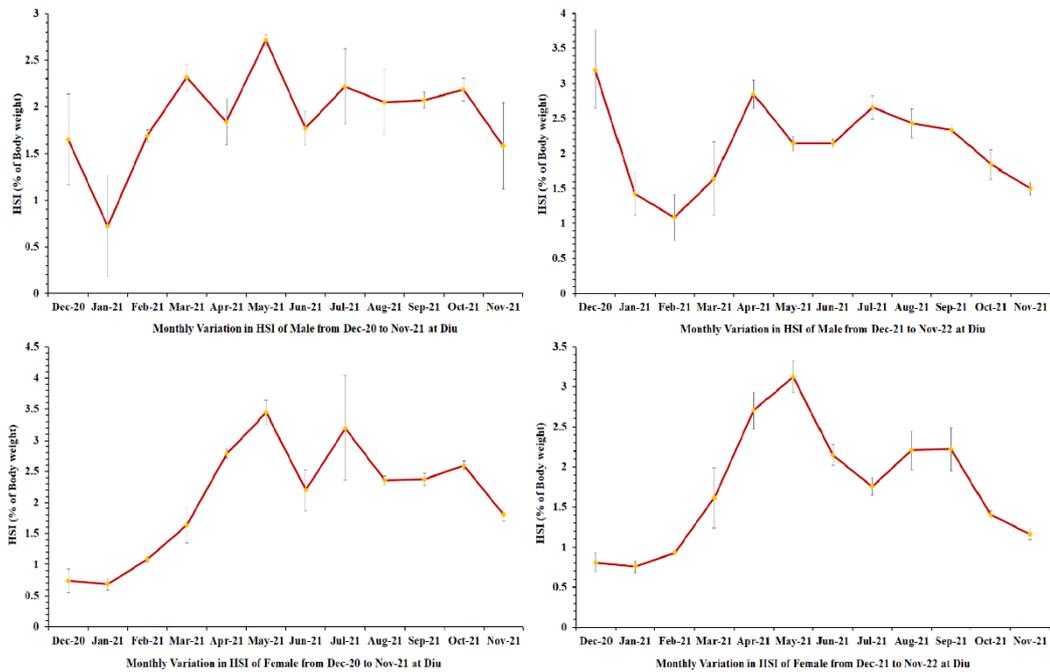


Figure 13: Monthly variation in Hepatosomatic Index (HSI) from December 2020 to November 2022 at Diu: (a) Male from Dec 2020 to Nov 2021, (b) Male from Dec 2021 to Nov 2022, (c) Female from Dec 2020 to Nov 2021, (d) Female from Dec 2021 to Nov 2022.

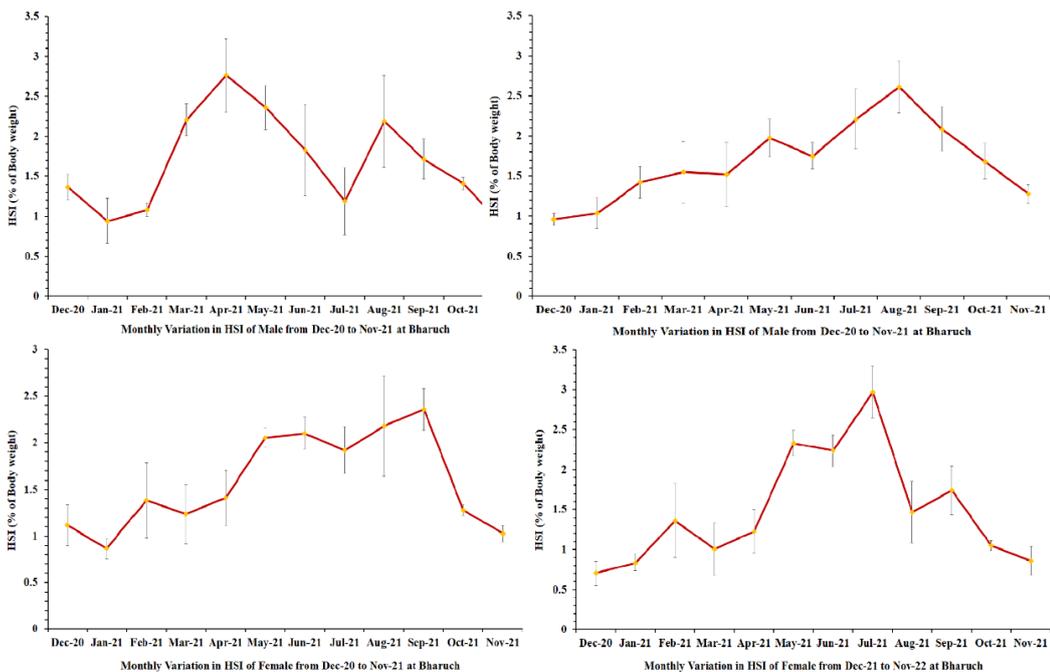


Figure 14: Monthly variation in Hepatosomatic Index (HSI) from December 2020 to November 2022 at Bharuch: (a) Male from Dec 2020 to Nov 2021, (b) Male from Dec 2021 to Nov 2022, (c) Female from Dec 2020 to Nov 2021, (d) Female from Dec 2021 to Nov 2022.

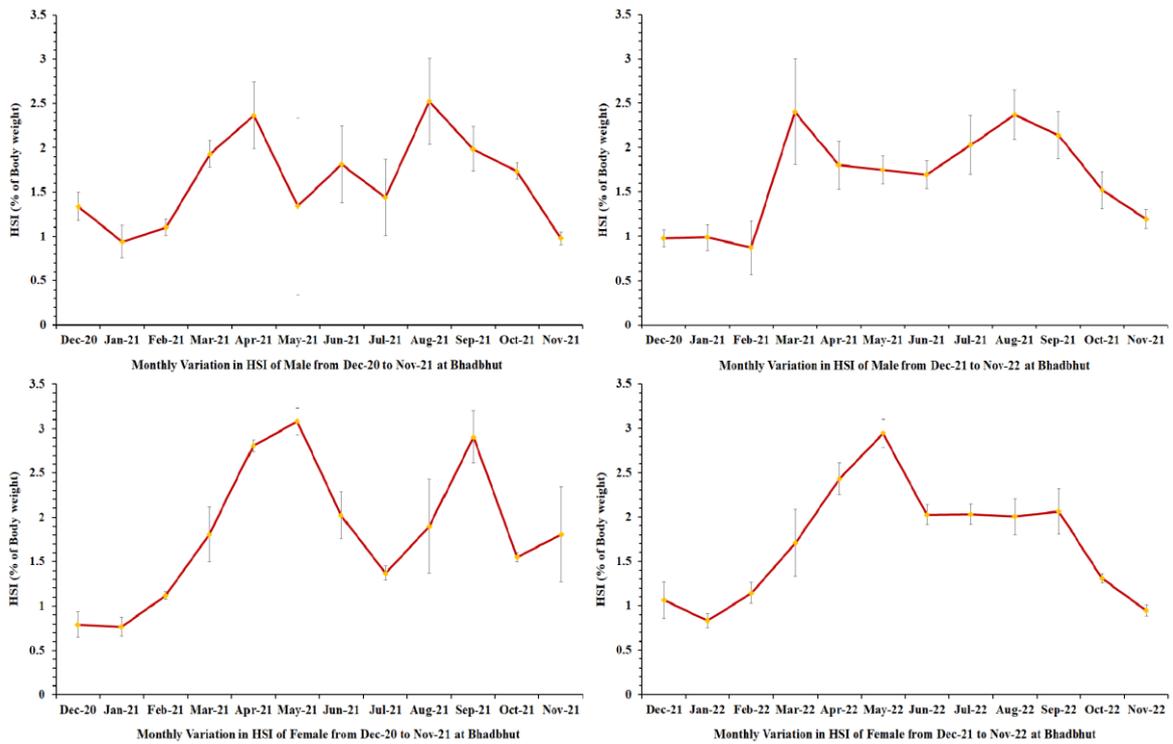


Figure 15: Monthly variation in Hepatosomatic Index (HSI) from December 2020 to November 2022 at Bhadbhut: (a) Male from Dec 2020 to Nov 2021, (b) Male from Dec 2021 to Nov 2022, (c) Female from Dec 2020 to Nov 2021, (d) Female from Dec 2021 to Nov 2022.

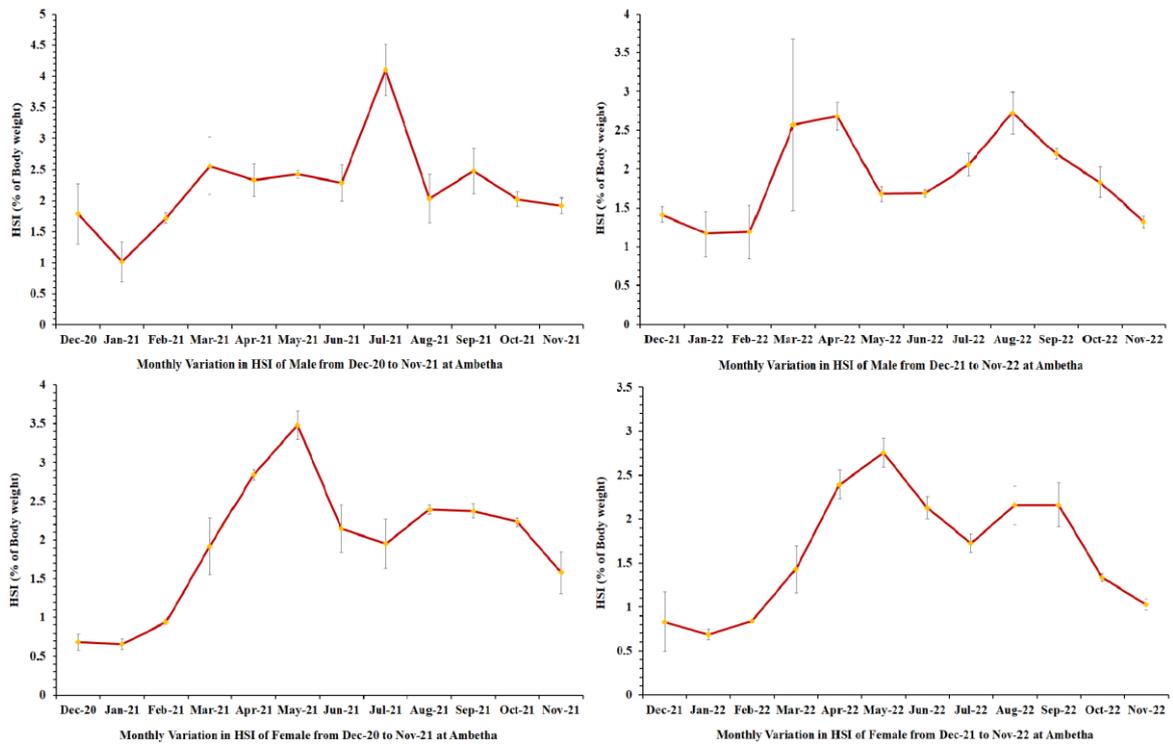


Figure 16: Monthly variation in Hepatosomatic Index (HSI) from December 2020 to November 2022 at Ambetha: (a) Male from Dec 2020 to Nov 2021, (b) Male from Dec 2021 to Nov 2022, (c) Female from Dec 2020 to Nov 2021, (d) Female from Dec 2021 to Nov 2022.

3a. A proximate analysis - Moisture, Total Ash, Total Fat, Total Protein and Carbohydrate content of *Mugil cephalus* (Linnaeus, 1758).

The moisture content results revealed that it ranges between 75-81%. Generally, it was observed higher in female population throughout the year compare to male population. The higher the concentration of moisture, the longevity of the fish also increases post harvesting (Figure 17). The ash content analysis revealed the concentration of minerals present in the body which ranged between 0.80-1.6%. Males were having low ash content compare to females. It also shows the higher ash content during post monsoon and winter (Figure 18). The protein content analysis indicates the amount of protein present in grams per 100 grams. The data revealed the range between 15-19 g/100g which is comparatively higher concentration makes it nutritious fish (Figure 19). The protein content was found higher in males compare to females. It maybe because female uses it as their energy requirements during fertilization. In figure 19, only on June month the protein content was higher in female, as this is the resting phase of the gonadal maturation. The lipid content was ranged between 0.60-1.20% of body weight (Figure 20). Females were showing higher difference in lipid content during pre-gonadal maturation period (August-October). During rest of the period, it shows minor difference in male and female. Lipid is also utilized by fishes during the reproductive cycle. The carbohydrates were found in very low concentration ranged between 0.15-0.45 mg/100mg from Diu lagoon (Figure 21).

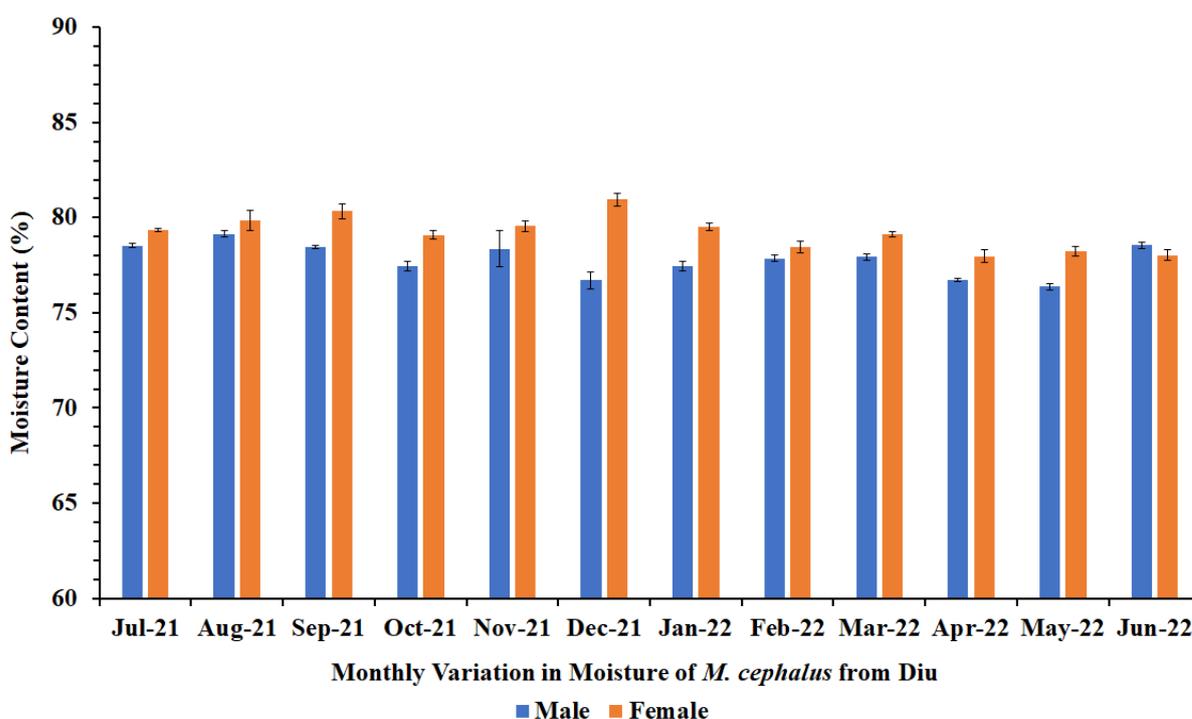


Figure 17: Moisture content analysis of male and female *M. cephalus* from Diu lagoon from July-2021 to June-2022.

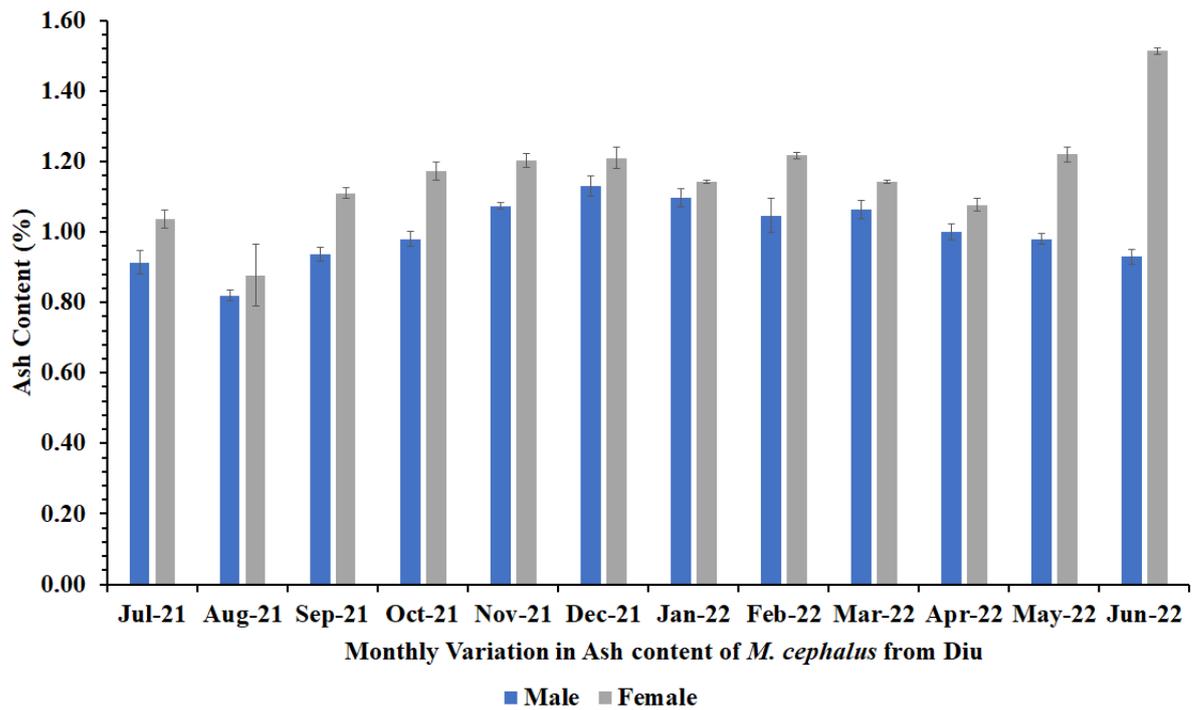


Figure 18: Ash content analysis of male and female *M. cephalus* from Diu lagoon from July-2021 to June-2022.

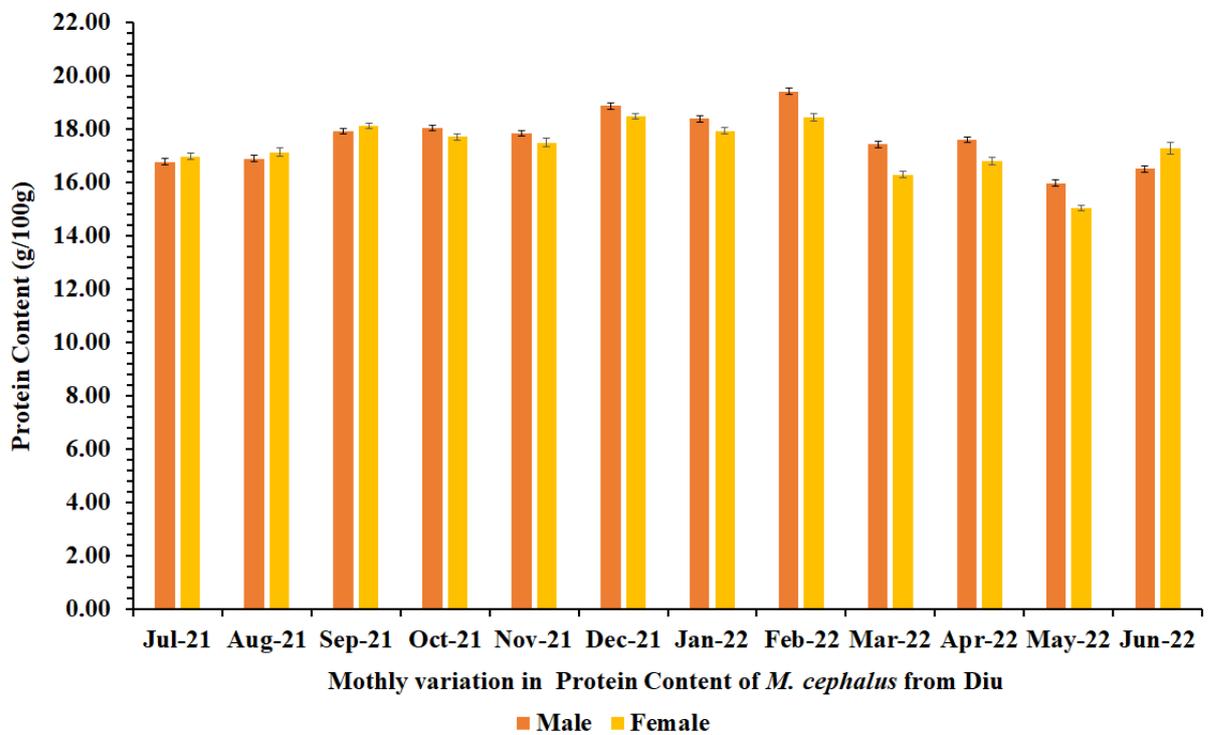


Figure 19: Protein content analysis of male and female *M. cephalus* from Diu lagoon from July-2021 to June-2022.

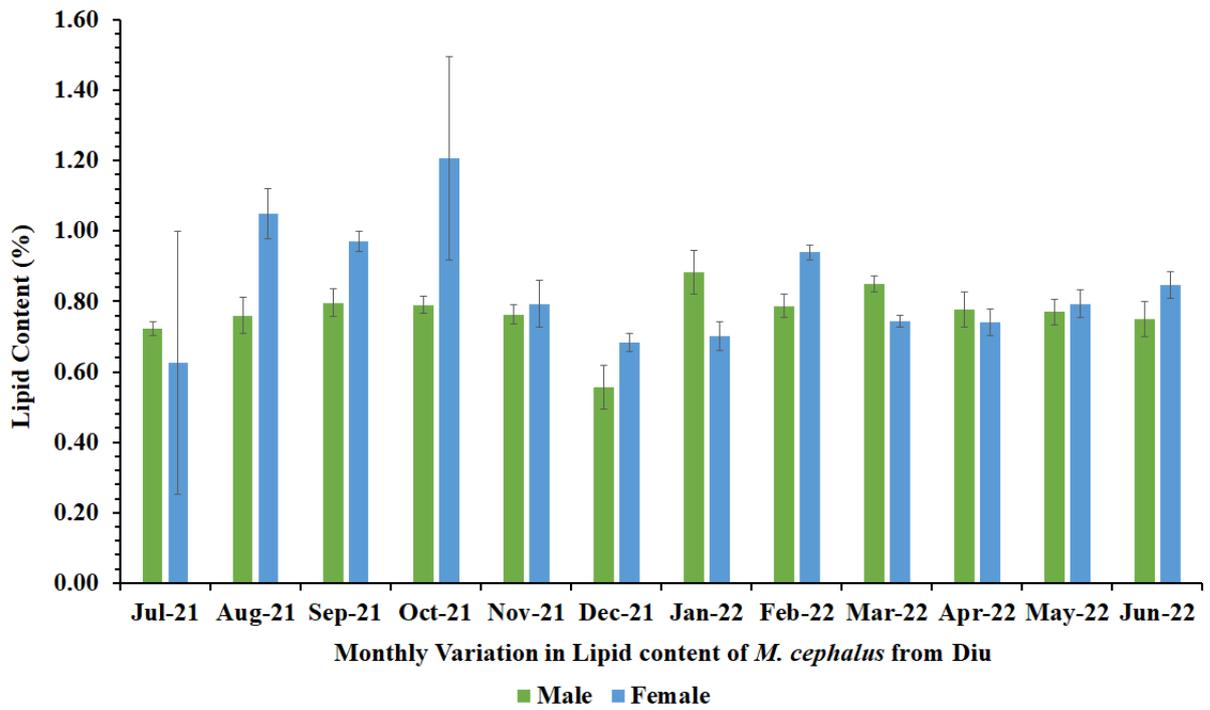


Figure 20: Lipid content analysis of male and female *M. cephalus* from Diu lagoon from July-2021 to June-2022.

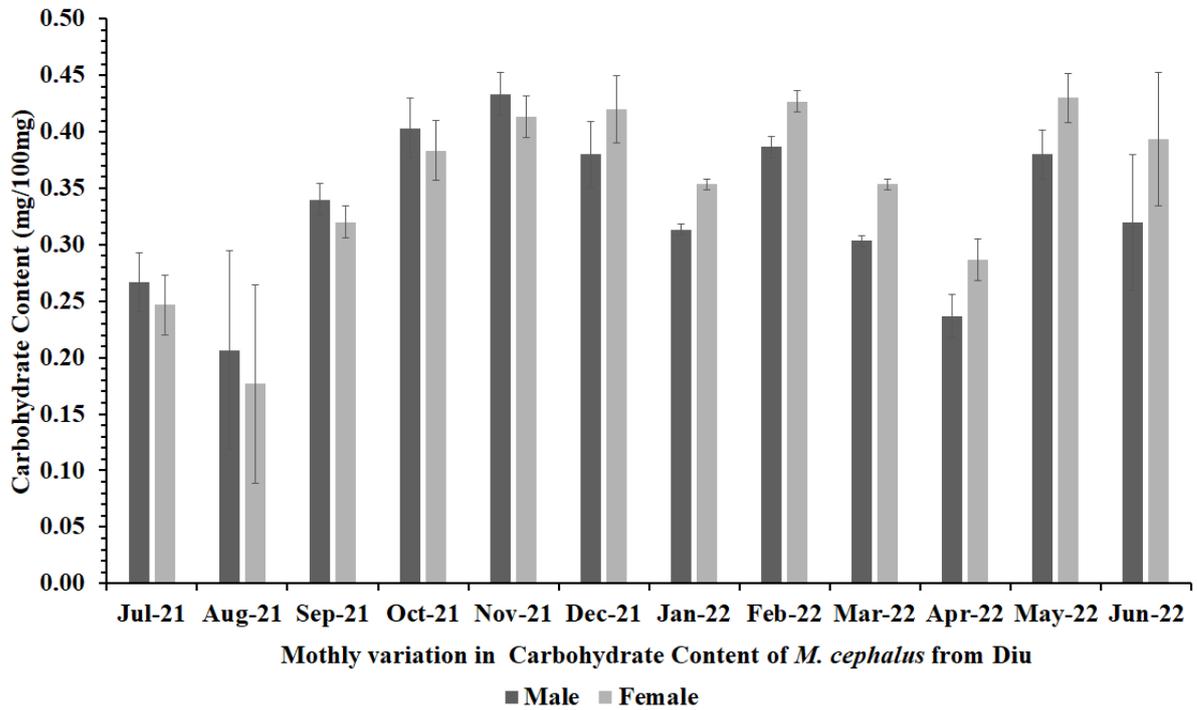


Figure 21: Carbohydrate content analysis of male and female *M. cephalus* from Diu lagoon from July-2021 to June-2022.

Outcomes:

During the study, a total of six species has been identified properly. Few species are under examination which may increase the number of species from the study.

The environmental parameters revealed the differences in both the habitats where *M. cephalus* is found.

The Length-Weight Relationship indicates the negative allometric growth which could be due to the environmental or anthropogenic stress.

The Fulton's Condition Factor shows the condition of the species in their respective habitats. The near the values to 1 represents the good condition of the species. The deviation shows due to the reproductive changes, food availability and environmental factors.

The Gonadosomatic Index and Hepatosomatic Index data indicates their interlinking as when GSI increase, the HSI decreases. This revealed that the hepatic energy has been consumed during the gonadal maturation.

The proximate content analysis revealed the amount of nutrients and moisture present in the species of respective habitats. The data revealed the position of the fish near to Hilsa and Salmon like highly nutritive species.

Therefore, the result reveals that the fish is accepted for aquaculture practices and identified as candidate fish for stocking into brackish water aquaculture ponds.

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Research Student

[Mr. Dhavalkumar Mukeshbhai Bhatt]

Research Guide

[Prof. P. C. Mankodi]

RESEARCH PUBLICATION

- 2022 An annotated checklist of family Mugilidae Jarocki, 1822 (Actinopterygii: Mugiliformes) from India, *Journal of Asia-Pacific Biodiversity*, 16(1), 5-19. ISSN 2287-884X, <https://doi.org/10.1016/j.japb.2022.09.011>
- 2022 Length–Weight Relationship, Condition Factor, Gonadosomatic Index and Gut-Content Analysis of *Planiliza planiceps* (Valenciennes 1836) (Actinopterygii, Mugiliformes, Mugilidae) from the Four Major Estuaries of Gujarat, India. *Thalassas: An International Journal of Marine Sciences*, 38, 855–864. DOI: <https://doi.org/10.1007/s41208-022-00422-8> [E-ISSN: 2366-1674]
- 2022 An updated checklist of family Theraphosidae Thorell, 1869 (Arachnida: Araneae) from India. *Munis Entomology & Zoology*, 17 (1): 74-85. [ISSN: 1306-3022]
- 2022 New record of spot-tail sleeper ray *Narke dipterygia* (Bloch and Schneider, 1801) (Elasmobranchii, Torpediniformes, Narkidae) from the coast of Gujarat, India. *Journal of Fisheries*, 10(1), 101401. [ISSN: 2311-3111] DOI: <https://doi.org/10.17017/j.fish.342>
- 2022 First record of *Neoheterophriectus smithi* Mirza, bhosale & sanap, 2014 (Arachnida, Araneae, Theraphosidae) from Gujarat, India. *International Journal of Entomology Research*, 7(1): 46-48. [ISSN: 2455-4758]
- 2022 Diversity of Intertidal Macrobenthic Flora and Fauna along the South Saurashtra Coastal Zone, Gujarat, India. *International Journal of Entomology*. 7(4), 130-142. [ISSN: 2455-4758]
- 2021 Length-Weight Relationship and Condition Factor of *Rhinomugil corsula* (Hamilton, 1822) (Actinopterygii, Mugiliformes, Mugilidae) in Four Major Estuaries of Gujarat, India. *Journal of Fisheries and Environment*, 45(3), 53-63. [eISSN: 2630-0826]
- 2021 Ichthyofaunal diversity and fishery status of Sutrapada Coast, Gujarat, India. *Journal of Fisheries*, 9(2), 92204. [ISSN: 2311-3111] DOI: <https://doi.org/10.17017/j.fish.291>
- 2021 An Annotated Checklist of Avifauna from Hemchandracharya North Gujarat University Campus, Patan, Gujarat, India. *Journal of Biological Studies*, 3(4), 121–131. [ISSN 2209-2560]
- 2020 Diversity record of family Mugilidae (Cuvier, 1829) from the estuary of Sabarmati River, Gujarat, India. *Journal of Biological Studies*, 3(2), 58–68. [ISSN 2209-2560]
- 2020 Study of Prevalence of tick *Hyalomma excavatum* (Acari: Ixodidae) on *Bubalus bubalis* in Patan District, Gujarat state, India. *Journal of Biological Studies*, 3(2), 69–78. [ISSN 2209-2560]

BOOK CHAPTERS

- 2022 Growth Index, Gonadosomatic Index and Gut-Content Analysis of *Mugil Cephalus* Linnaeus, 1758 Found in Three Major Estuaries of Gujarat, India, 21-33. *In: Proceedings of National Conference on Present Day Biology: Recent Advancements in Biological Sciences*. ISBN No: 978-93-9996-06-3
- 2018 The Diversity of Skates and Rays from Saurashtra Coast-The Peninsular Region of Gujarat, India. *In: Proceedings of National Conference on Present Day Biology: Recent Advancements in Biological Sciences*. ISBN No: 978-93-9996-06-3

ORAL & POSTER PRESENTATION

- 1st Rank Oral Presentation in **International** seminar on Restore Our Earth - **Apr 2021** ICORE 2021 organized by Department of Environmental Sciences, Bishop Heber College, Tamil Nadu India
- 1st Rank Oral Presentation in **National** Conference on Present Day Biology: **Dec 2021** Recent Advancements in Biological Sciences organized by the Department of Biochemistry-Biotechnology, St. Xavier's College (Autonomous), Ahmedabad
- 1st Rank Oral Presentation in Science Excellence-2018 (Faculty Category) at **Sep 2018**

- Gujarat University Ahmadabad
- Presented a poster in **National** Seminar on Bio-Sciences at Sankalchand Patel **Jan 2018** University, Visnagar
 - Presented poster in Science Excellence-2015 organized by The Gujarat **Sep 2015** University.
 - Oral Presentation in Wildlife Week 2014 organized by the Department of **Oct 2014** Zoology, The Maharaja Sayajirao University of Baroda, Vadodara

WORKSHOP/CONFERENCE ATTENDED

- Virtual Workshop on "High-Density Continuous Production of Marine Copepods organized by the Department of Marine Science, Bharathidasan University, Tiruchirappalli-24, India **Apr 2022**
- Webinar on "Essentials of Scientific Writing" at Biomedical Engg. Department, L.D. College of Engineering. **Feb 2022**
- Hands-on Training on Basic Molecular Biology Techniques, Jointly Organized by Gujarat Biotechnology Research Centre, Gandhinagar and Gujarat Technological University, Ahmedabad **Oct 2021**
- Webinar on "Citation and Reference Management" - organized by AOZ - Association of Zoologists **Sep 2021**
- Webinar entitled "Fantastic animals and How to identify them" - A talk on planning and publishing taxonomic studies on animals organized by AOZ - Association of Zoologists **Sep 2021**
- Webinar on World Oceans Day with theme "Marine Ecosystem: Conservation and Challenges" jointly organized by Dept. of Biology, Shri R. R. Lalan College, and Association of Zoologists **Jun 2021**
- International Webinar on "Scientific Writing" – organized by the Department of Chemistry, IIS, Jaipur in association with Association of Chemistry Teachers (ACT), Mumbai **Nov 2020**
- Webinar on "Inter-Specific Competition for Nest box Cavities in Savannah Environment" – conducted by the Department of Zoology, The Maharaja Sayajirao University of Baroda, Vadodara **Nov 2020**
- Three days' workshop on "DNA Taxonomy and Phylogeny" organized by Sathyabama Institute of Science and Technology, Chennai **May 2020**