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Ichthyoarchaeological perspectives on roles of fish and red meat during Indus Civilization in Gujarat, India

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The roles of animals during the Indus Civilization (circa 4000 BCE to 1300 BCE), which thrived in South Asia, have been extensively studied by zooarchaeologists. While significant progress has been made in understanding the domestication and hunting of mammals, information on the use of aquatic organisms such as fish, mollusks, and crustaceans has been relatively sparse. Excavations at Indus Civilization sites have uncovered substantial quantities of fish remains, potentially providing valuable insights. In South Asia, the study of fish remains has often been neglected, primarily due to the lack of comprehensive reference collections for comparison. This paper discusses the current state and future possibilities of South Asian ichthyoarchaeology, highlighting the results of ichthyoarchaeological investigations in the Gujarat region of India. Analysis of fishbone assemblages from Indus sites such as Bagasra, Kanmer, Shikarpur, Kotada Bhadli, and Navinal in Gujarat has identified 24 fish species from 14 families. Evidence of anthropogenic activities such as cut marks, charring, and chewing on the bones suggests various aspects of fish consumption. These analyses reveal information about the diversity of fish species used, fishing environments, changes in fish consumption across different cultural phases, spatial distribution of fish remains within the sites, and fish processing patterns. The ichthyoarchaeological data aligns with cultural changes inferred from archaeobotanical and non-fish faunal records from these sites. This paper offers insights into a more nuanced role of fish in the diet, tailored to the tastes and preferences of consumers, rather than being a secondary or incidental food source, alongside mammalian meat during the Harappan Civilization in the Gujarat region.

KEYWORDS

Harappan Civilization, ichthyoarchaeology, fishbones, species identification, aquatic fauna, subsistence economy, fish consumption, Kachchh in Gujarat

1 Introduction

The Indus/Harappan Civilization, South Asia's first urban civilization, thrived over an area exceeding 1 million square kilometers between ∼4000 and 1300 BCE (Kenoyer, 2011). It stretched from Shortugai in northern Afghanistan to Daimabad in the south, Manpur in the east in India, and Sutkagendor in the west in Pakistan, collectively known as the Greater Indus Region. This civilization can be divided into three cultural phases: the Early Harappan (c. 4000–2600 BCE), the Mature Harappan (c. 2600–1900 BCE), and the Late Harappan (1900–1300 BCE). During the Early Harappan phase, distinct regional cultures emerged, with individuality reflected in ceramics and other artifacts. These Chalcolithic cultures had developed subsistence systems, interregional networks, technological innovations, and social hierarchies, setting the stage for the rise of an urban, state-level society. In the Mature Harappan phase, the civilization evolved into a vast, interconnected urban society. It has over 3,000 sites, including five major cities: Harappa, Mohenjodaro, Ganweriwala, Rakhigarhi, and Dholavira. The society was marked by a network of fortified settlements, skilled craftsmanship, and the use of standardized weights and measures. Distinctive seals, evidence of long-distance trade, and a mixed economy based on agriculture and pastoralism further highlight the complexity of this civilization. The subsequent Late Harappan phase saw the decline of the Indus Civilization, as regions became increasingly differentiated. Some technological traditions, such as stone bead and shell bangle production, continued, while others, including the carving of inscribed steatite seals and the use of standardized weights, disappeared. Long-distance trade networks also collapsed, limiting the distribution of goods to areas close to raw material sources (Possehl, 1990, 1999, 2002; Kenoyer, 1991, 1998; Wright, 2010).

In the southern part of the Indus Civilization, corresponding to the modern Indian state of Gujarat, evidence for Chalcolithic communities is available from the early 4th millennium BCE, as evidenced by Early Harappan sites like Loteshwar in North Gujarat and Padri in Saurashtra. As a peripheral zone with diverse ecological settings and a wide distribution of settlements, Gujarat played a significant role in the Harappan Civilization. Research on the Indus Civilization in Gujarat has provided a clearer understanding of its chronology, ceramic traditions, and settlement patterns than in other parts of the Greater Indus Region (Bhan, 1994; Ajithprasad, 2002, 2004; Chase et al., 2020). The regional Chalcolithic traditions in Gujarat, such as Anarta, Padri, Pre-Prabhas, Sorath Harappan, Micaceous Red Ware, Prabhas, and Lustrous Red Ware, correspond to the Early, Mature, and Late Harappan phases of the Indus Civilization. In Gujarat, these phases span roughly from 3900 to 1300 BCE (Rajesh, 2018) (Figure 1).

Gujarat is situated along the Tropic of Cancer and forms a significant part of the arid region of western India, adjacent to the Thar Desert. It is bordered to the north and east by mountain ranges, including the southern Aravalli Hills, the western edge of the Vindhyas, the Satpura ranges, and the northern portion of the Western Ghats (Deshpande, 1948). To the south and west, Gujarat is flanked by the sea, featuring two prominent marine extensions: the Gulf of Khambhat and the Gulf of Kachchh. Gujarat comprises four geographic regions: the alluvial plains of mainland Gujarat, divided by the Mahi River into the more arid North Gujarat and wetter South Gujarat, the peninsula of Saurashtra, and the Kachchh region. The Kachchh region is geographically distinct, with its crescent-shaped disposition and four geomorphic units. The Great and Little Ranns are vast salt plains that flood with seawater and river runoff during monsoons, leaving dry, salt-encrusted mud in other seasons. The low-lying Banni Plains provide a unique grassland ecosystem that supports pastoralism. The hilly regions consist of a rocky and arid landscape dotted with sedimentary Jurassic rocks and Deccan Trap layers, while the southern coastal plains feature dissected surfaces shaped by river erosion, coastal lowlands, creeks, and sand dunes bordered by cliffs. The region's freshwater drainage system comprises ephemeral streams and ponds (Biswas, 1993; Merh, 1995; Chamyal et al., 2003) (Figure 1).

The climate and environment of Gujarat during the Harappan period have been widely debated, with scholars divided over whether it was wetter or similar to the present. Early proponents (Marshall, 1931; Stein, 1931) suggested a wetter climate, a view later supported by studies (Singh, 1971; Chamyal et al., 2003; Maurya et al., 2008; Singhvi and Kale, 2009; Tyagi et al., 2012). However, subsequent research suggests increasing aridification, aligned with the Meghalayan Stage drought, which led to the silting and drying of the Gulf of Kachchh between 4300 and 4100 BP (Dixit et al., 2014; Pokharia et al., 2017; Sengupta et al., 2020).

2 Animal-based subsistence of Indus Civilization and status of fish

The roles of animals during the Indus Civilization have been extensively studied by zooarchaeologists since the initial excavations at Harappa and Mohenjodaro (e.g., Prashad, 1936). While significant progress has been made in understanding animal domestication and the hunting of mammals for food and other purposes, information on the use of aquatic organisms, such as fish, mollusks, and crustaceans, remains relatively sparse (Abhayan, 2016; Deshpande-Mukherjee, 2023).

During the Harappan Civilization, animal-based subsistence across the Greater Indus region relied primarily on pastoralism, particularly involving bovines and caprines. Cattle (*Bos indicus*) were the predominant category, along with buffalo (*Bubalus bubalis*), sheep (*Ovis aries*), and goats (*Capra hircus*). Additionally, the diet included other mammals such as pigs (*Sus domesticus*), various wild mammals (e.g., antelope, deer, wild boar, and hare), as well as birds, reptiles, mollusks, and fish (Misra, 1988; Sahu, 1988; Meadow, 1989, 1996; Badam and Sathe, 1991; Thomas and Joglekar, 1994; Thomas et al., 1997; Chattopadhyaya, 2002; Meadow and Patel, 2002, 2003; Thomas, 2002; Goyal, 2021).

Ichthyoarchaeology, the study of fish remains from archaeological sites, holds great potential for revealing aspects of subsistence practices while offering insights into past environmental conditions and complex social activities (Casteel, 1976; Wheeler and Jones, 1989). In South Asia, fish remains have been recorded since the 1924–31 excavation seasons at Harappa (Prashad, 1936). However, compared to other regions,

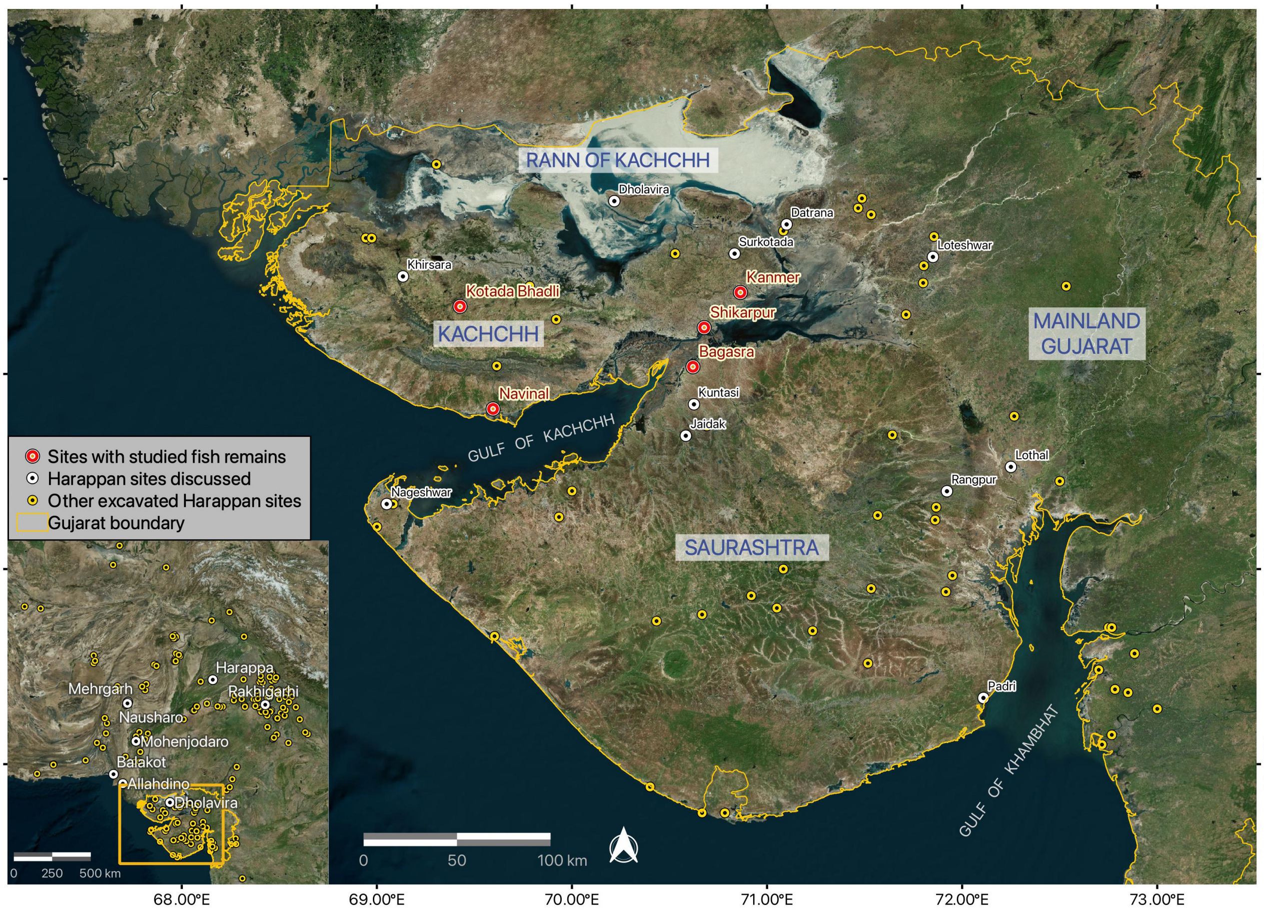

FIGURE 1
Map showing excavated Harappan/Chalcolithic sites, with labels for the specific sites discussed in the article (Image composed by Abhayan G.S., using Bing Satellite imagery as the base map in QGIS).

fish remains have not been systematically studied, largely due to inadequate laboratory facilities and a lack of comparative reference collections for fish in the area. Globally, even though ichthyoarchaeological studies faced challenges stemming from insufficient comparative reference collections, significant progress has been made in many regions (Ryder, 1969; Casteel, 1976; Wheeler, 1978; Wheeler and Jones, 1989; Colley, 1990; Belcher, 1998; Morales-Muñiz, 2014).

In South Asia, in addition to the lack of reference collections, there is often a lack of awareness among excavators regarding the importance of collecting small bone remains. Adequate recovery methods, including both dry and wet sieving of excavated sediments, are infrequently employed, leading to the hand collection of only easily visible bones, typically medium and large-sized mammals, while smaller faunal remains, including fish, are often overlooked. Specific, objective-oriented faunal analyses that focus on qualitative and quantitative assessments of livestock management have yielded significant results but often compromised the study of fish remains. The fish remains collected alongside other faunal samples during excavations, though limited in numbers, have frequently undergone analysis by zooarchaeologists, resulting in vague identifications and minimal interpretations (e.g., Shah and Bhan, 1990; Chase, 2007; Joglekar and Goyal, 2011).

In the Indian Subcontinent, notable ichthyoarchaeological research has been conducted by Belcher (1998), who investigated fish exploitation by the Harappans in Pakistan, and by Abhayan (2016), who studied the fish remains from the Gulf of Kachchh region in Gujarat. These studies were facilitated by the development of regional reference collections of fish. Furthermore, taxonomic identification of fish otoliths has been undertaken, along with analyses of their implications for archaeological contexts (Abhayan et al., 2016; Krishna, 2017). Otoliths of *Ophicephalus* sp. were utilized to assess changes in the hydrological features of regions bordering the Little Rann of Kachchh in North Gujarat during the early third millennium BCE (Ajithprasad, 2004). Stable isotope ratios in fish remains have also been employed as environmental proxies, as demonstrated by the analysis of ancient fish otoliths from Bagasra in Gujarat. This research indicates that the minimum temperature in the Gulf of Kachchh region around 4300 BP was ~2.5°C lower than it is today (Amekawa et al., 2016).

Another area of concern is the limited integration of ethnographic and ethnoarchaeological studies with artifacts relevant to archaeological contexts (cf. Nagar, 1982; Ansari, 2001;

Ruikar, 2013). The potential for extensive studies related to fishing-related archaeological findings remains underexplored. This paper provides a detailed assessment of the role of fish in the subsistence practices of the Harappan Civilization in the Gujarat region, with a close comparison to other faunal remains, primarily those of mammals.

3 Materials and methods

Detailed zooarchaeological investigations of non-fish faunal remains have already been conducted independently for the selected sites, viz. Bagasra, Kanmer, Shikarpur, Navinal and Kotada Bhadli (Chase, 2010, 2014; Goyal et al., 2018; Ajith et al., 2019; Goyal, 2021) (Figure 2). However, detailed and precise studies of fish remains have not been undertaken in these investigations. Sample selection for the current study was done in consultation with previous faunal researchers and excavators to ensure a representation of as many occupational phases and specific contexts as possible while avoiding ambiguous contexts caused by disturbances in the stratigraphy. For Kanmer, samples representing the Harappan phases (KMR I, IIA, IIB, and III) were chosen, while later phases (KMR IV and V) were excluded. At Navinal, samples were collected from the exposed surface of the site rather than stratigraphic contexts, but because the site is single-culture, the fish assemblage was considered together. The rest of the samples from the other four sites came from excavated contexts with stratigraphic correlations to their respective phases. One limitation of the excavated trenches is that they do not represent all occupational phases evenly, which affects the sample sizes. The specific trenches from which the studied samples were taken are indicated in the site plans (Figure 2).

For fish identification, the study primarily relied on an osteological reference collection of fish and identification keys developed by the first author (Abhayan, 2016), housed in the Zooarchaeology laboratory in the Department of Archaeology, University of Kerala. Additional published sources were used for species identification, including Fischer and Bianchi (1984) and Disspain et al. (2016). Casteel (1976), Lepiksaar (1994), and Wheeler and Jones (1989) were used for fish osteology. Fish bones that were identified to a taxonomic category, Order, Family, Genus, or Species, were considered as Number of Identified Specimens (NISP). In many cases, a specific species could not be assigned to a bone fragment due to the large number of closely related species within certain fish families. The Minimum Number of Individuals (MNI) was calculated; however, it is not significantly more reliable than the Number of Identified Specimens (NISP) due to factors such as extensive bone fragmentation, varying bone sizes, and challenges in determining side identification.

The bone elements with the highest diagnostic value for species identification included jawbones (dentary, premaxilla, maxilla, articular, and quadrate), the preoperculum, operculum, cleithrum, and certain cranial bones. Other elements, such as modified scales, spines, teeth, and pharyngeal plates, were also often diagnostic. Bone elements that could not be identified beyond the level of 'Teleostei' (bony fishes) were categorized separately and quantified apart from the NISP. This category includes nearly complete elements like fin rays, pterygiophores, vertebrae, and ribs, which are referred to as 'Undiagnostic' due to the absence of distinctive features. These elements were still recorded, as they can carry supplementary information such as cut marks or charred features. The identification of vertebrae to taxonomic categories was challenging in the present assemblages. While species-level identification of vertebrae has been successfully achieved in temperate regions (e.g., Casteel, 1976; Wheeler, 1978) and even in tropical regions of Southeast Asia (e.g., Ono and Clark, 2012; Lambrides and Weisler, 2015a,b; Boulanger et al., 2023), most vertebrae in the current assemblages were identified as broader categories of estuarine fish but could not be classified to the specific family level. However, vertebrae were not entirely excluded; select specimens with anatomically distinct shapes were included in the NISP. The study utilized a recently developed reference collection, underscoring the need for more comprehensive identification keys specific to the study region.

4 Brief cultural background of the selected sites

Numerous propositions have been made regarding the terminology of different phases of the Harappan civilization to elucidate its cultural complexity (Mughal, 1970; Allchin and Allchin, 1982; Konishi, 1984; Possehl, 1984; Jansen, 1993). The most commonly accepted terms for denoting the Harappan periods include the Early Harappan (c. 4000–2600 BCE), the Mature Harappan (c. 2600–1900 BCE), and the Late Harappan (1900–1300 BCE). These three designated Harappan periods correspond to three eras (out of four eras proposed): the Regionalization Era, the Integration Era, and the Localization Era, respectively (Shaffer, 1992). Possehl (1992:118) proposed an alternative terminology based on socio-cultural and technological developments, categorizing them as Pre-Urban, Urban, and Post-Urban. Several sub-phases have been identified within each of these phases, reflecting the observed cultural changes. Of the ∼800 reported sites in Gujarat, many have been excavated to varying extents (Figure 1). Each site has been described and classified using the terminology preferred by the excavators. A brief background on the five selected sites for this study is provided below (Table 1).

4.1 Bagasra

Bagasra (23° 02′ 12 "N, 70° 37′ 11" E) is located about half a kilometer southeast of the modern village of Bagasra in Maliya Taluka, Morbi District (formerly Rajkot District), Gujarat. The site, also referred to as Gola Dhoro in earlier publications, covers ∼2 hectares and is nearly rectangular in shape, though it is relatively small compared to other urban Harappan sites. It lies about a kilometer from a creek extending from the Gulf of Kachchh. Excavations, conducted by the Department of Archaeology, The Maharaja Sayajirao University of Baroda between 1996 and 2005, revealed a 7.50 m thick habitation deposit divided into four cultural phases. These phases were determined based on stratigraphy, diagnostic artifacts, structural features, and radiocarbon dating (Sonawane et al., 2003; Bhan et al., 2004, 2005). Various reports (IAR 1965-66, 1973; IAR 1995-96, 2002; IAR 1996-97, 2002; IAR

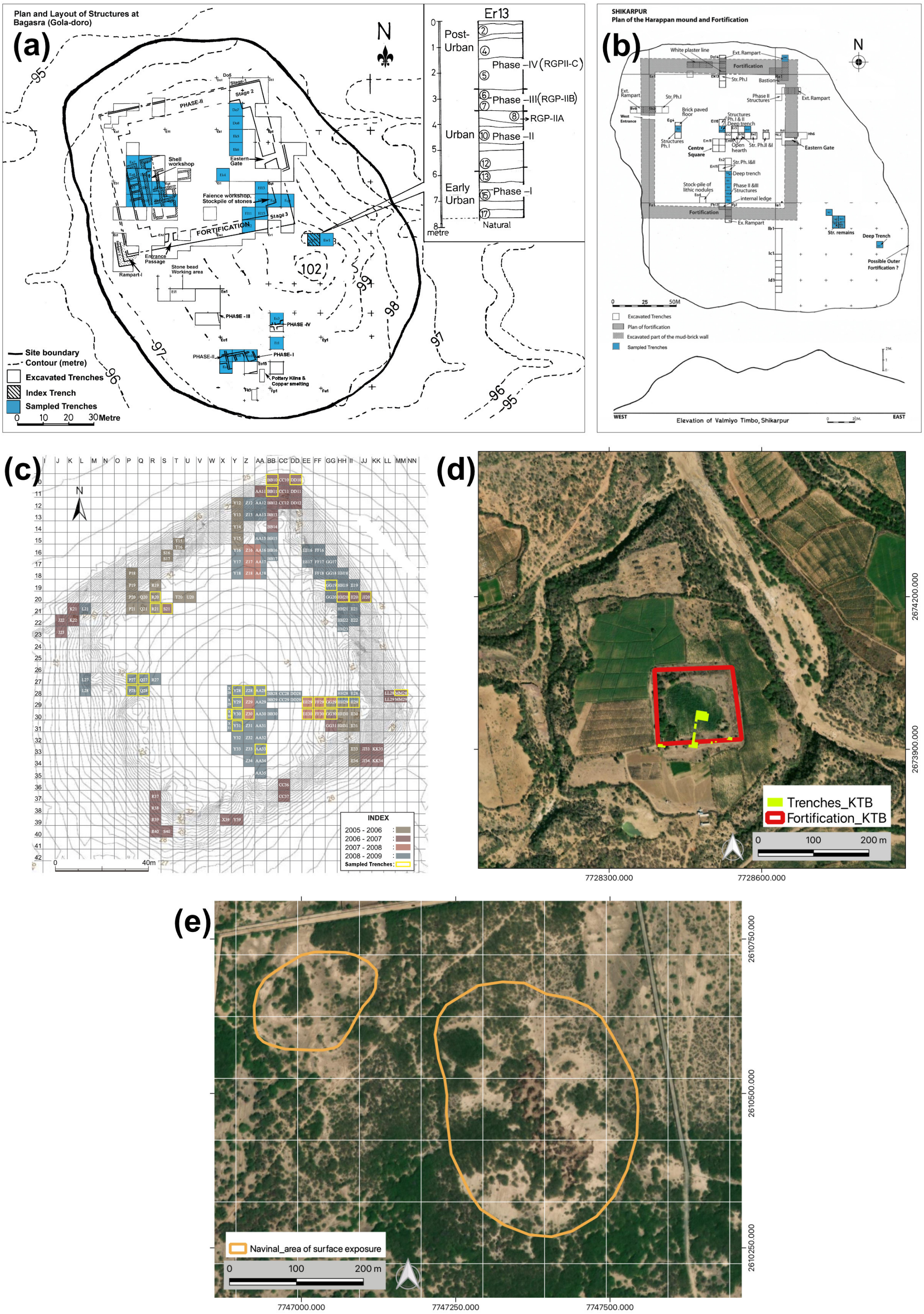

FIGURE 2
Plans of selected sites showing fortifications, and sampled excavation trenches. **(A)** Bagasra (Image Courtesy: MSU Baroda), **(B)** Shikarpur (Image Courtesy: MSU Baroda), **(C)** Kanmer (After Kharakwal et al., 2012a), **(D)** Kotada Bhadli (Image composed by Abhayan G.S.), and **(E)** Navinal (Image composed by Abhayan G.S.).

TABLE 1 Cultural sequence and affiliations of material culture from Bagasra, Kanmer, Shikarpur, Navinal, and Kotada Bhadli.

Cultural sequence		Material culture	Bagasra (BSR)	Kanmer (KMR)	Shikarpur (SKP)	Navinal (NVL)	Kotada Bhadli (KTB)
Mature Harappan (C.2600-1900 BCE)	Phase I (c. 2600-2200 BCE)	CH + A	BSR I and BSR II	KMR I and KMR IIA	SKP I	-	-
	Phase II (c. 2200-1900 BCE)	CH + SH + A	BSR III	KMR IIB KMR III	SKP II	NVL I	KTB I*
Late Harappan (c. 1900-1700 BCE)	Phase III (c.1900-1700 BCE)	LSH	BSR IV	-	SKP III	NVL II	KTB II

CH, Classical Harappan; A, Anarta; SH, Sorath Harappan; LSH, Late Sorath Harappan.
*Anarta pottery has not been found at Kotada Bhadli. Although a significant number of Late Sorath Harappan ceramics are present at the site, they are categorized under the Mature Harappan phase.

1997-98, 2003; Sonawane et al., 2003; IAR 1999-2000, 2005), doctoral dissertations (Chase, 2007; Law, 2008; Lindstrom, 2013; Gadekar, 2014) and other publications (Deshpande-Mukherjee, 1999; Bhan et al., 2004, 2005; Patel, 2006; Chase, 2010; Vinod, 2013; Chase et al., 2014, 2020; Gadekar et al., 2015) have provided a comprehensive understanding of the site.

The earliest occupation at Bagasra (Phase I), dating to the early Urban Harappan period (c. 2600 BCE), is marked by the presence of Harappan Black-on-Red pottery, Anarta pottery, and local bichrome slipped pottery, along with Harappan material culture such as Rohri chert blades, stone weights, terracotta toys, and lapis lazuli beads. Phase II saw the construction of a mud-brick fortification, along with seals, graffiti-marked ceramics, and increased craft activities, particularly in shell, faience, and stone bead manufacturing, indicating prosperity and economic stratification within the fortified area. Phase III, designated as the late Urban Harappan, reveals signs of disorganization, the decline in craft activities, and a predominance of Sorath Harappan pottery over Classical Harappan types, although Harappan artifacts like beads and seals remained in use. Phase IV (c. 1900–1700 BCE) is characterized by flimsy, reused structures and the dominance of Sorath Harappan pottery, with a notable absence of Classical Harappan artifacts, signaling a further decline in economic and cultural complexity (Bhan and Gowda, 2003; Sonawane et al., 2003) (Table 1).

Brad Chase (2007, 2010) analyzed meat provisioning at Bagasra using faunal remains and ethnographic models from Punjab, focusing primarily on mammalian fauna. Archaeozoological studies from other nearby Harappan sites, such as Shikarpur, were integrated with findings from Bagasra (Chase, 2014). Additionally, animal movement across the region was investigated by analyzing biogenic isotope ratios (Strontium, Carbon, and Oxygen) in the tooth enamel of domestic animals from Bagasra (Chase et al., 2014, 2020), exploring intra- and inter-individual variations to trace mobility patterns.

4.2 Kanmer

The archaeological mound known as Bakar Kot, located near the village of Kanmer in Rapar Taluka, Kachchh District, Gujarat (23°25′04″ N, 70°51′48″E), was excavated between 2005 and 2010 by a joint team from the Institute of Rajasthan Studies (Udaipur, Rajasthan), the Gujarat State Department of Archaeology, and the Research Institute for Humanity and Nature (Kyoto, Japan). The site, covering more than a hectare (115 m E-W, 105 m N-S), is roughly squarish and situated at an elevation of 29 m above sea level. It is drained by a seasonal rivulet originating from a nearby hillock in the northwest (Kharakwal et al., 2012a,b).

According to Kharakwal et al. (2012a) the excavations at Kanmer revealed five distinct cultural phases: KMR I (Early Harappan), KMR II (Mature Harappan), KMR III (Late Mature Harappan), KMR IV (Early Historic), and KMR V (Medieval). The first three phases of the Harappan time frame are discussed here, excluding the later two phases.

KMR I (Early Harappan/Early Mature Harappan) is a pre-fortification phase found in the central and western parts of the mound, with no structural remains but with three successive floor levels. The ceramics include red wares, bichrome, and cream-slipped pottery, similar to Anarta, linking the phase to other Early Harappan sites like Dholavira and Surkotada. KMR II (Mature Harappan) is divided into sub-phases KMR IIA and IIB. KMR IIB introduces new pottery types like white-painted Black-and-Red Ware and Sorath Harappan pottery. A fortification wall, advanced craft activities, and residential structures built around open spaces mark this phase as prosperous. Harappan script, seals, and graffiti were also found. KMR III (Late Mature Harappan) shows a decline in material culture, with deteriorating pottery quality and reduced quantities of typical Harappan artifacts. Craft activities and urban planning also declined, with streets and fortifications falling into disuse (Kharakwal et al., 2011, 2012a) (Table 1).

The faunal remains were thoroughly studied by Pankaj Goyal, providing a comprehensive understanding of animal-based subsistence at Kanmer (Goyal, 2011, 2021).

4.3 Shikarpur

The Harappan site of Shikarpur (23° 14′ 16“ N, 70° 40′ 39” E), also known as Valamiyo Timbo, is located about 4.5 km south of the modern village of Shikarpur in Bhachau taluka, Kachchh district, Gujarat. The site, covering approximately 5 hectares with 1.5 hectares enclosed within the walls, lies on the edge of a narrow creek extending from the Gulf of Kachchh and is formed atop a stabilized sand dune with a mound reaching about 7.5–8 m above the surrounding area. Excavations first conducted by the Gujarat State Department of Archaeology (1987–1990) revealed both Early (Pre-Urban) and Mature (Urban) Harappan cultural layers, with findings including ceramics, toy carts, terracotta figurines, shell beads, and copper objects, though detailed results were not published. Later excavations conducted by The Maharaja Sayajirao University of Baroda (2007-08 to 2013-2014) aimed to clarify the site's cultural sequence and its role in the regional Harappan network, especially in relation to the nearby site of Bagasra. The excavations revealed a massive fortification wall, ∼103 × 103 m^2 in plan, made of mud bricks, with a height of 6.3 m and a thickness of 9 m at the top, potentially more than 12 m at the base. Built during three stages, the wall rested on natural sediments and was initially covered with whitish clay plaster, with later-added rampart support. Excavations also uncovered an open central area surrounded by structures of mud bricks and rubble stones. Notable artifacts include a potsherd with cloth impressions, Rohri-chert blades, terracotta figurines, a copper celt, a carved bone object, and two seals, including a steatite button seal. Information on the excavations can be pieced together from various sources such as doctoral dissertations and published articles (Bhan, 1994; Bhan and Ajithprasad, 2008; Chase, 2014; Gadekar, 2014).

Though the former excavation revealed Mature and Early Harappan cultural horizons, the latter excavation brought to light a 3-fold cultural sequence at the site: Phase I (Classical Harappan), Phase II (Classical Harappan and Sorath Harappan), and Phase III (Late Sorath Harappan). The previously reported Early Harappan deposits were not found in the later excavation. Phase I at Shikarpur features a ceramic assemblage consisting of Classical Harappan pottery along with Anarta pottery, with some Sorath Harappan pottery appearing in the mid-levels. Phase II is characterized by the prominence of Sorath Harappan pottery, though Classical Harappan and Anarta tradition pottery are also present. Phase III revealed Late Sorath Harappan ceramics (Bhan, 1994; Bhan and Ajithprasad, 2008; Joglekar and Goyal, 2011) (Table 1).

The faunal materials from Shikarpur were studied by three different groups of researchers at three different times (Thomas et al., 1995; Joglekar and Goyal, 2011; Chase, 2014).

4.4 Navinal

Navinal (22° 49 17.5 N, 69° 35 49.9 E), located in the Mundra Taluka of Kachchh District, Gujarat, was discovered by P.P. Pandya in the 1950s and reported by S.R. Rao in 1963. The site, associated with the Rangpur IIB and IIC phases of the Harappan Civilization, shows evidence of both the Mature and Late Harappan phases. Surface surveys conducted from 2013 to 2017 and two test pits excavated in 2015 revealed a wealth of cultural remains, including ceramics such as Classical Harappan, Sorath Harappan, Late Sorath Harappan, Anarta Tradition, and Reserved Slip ware. Other findings include terracotta objects, shell bangles, stone and copper tools, and a large number of fish otoliths, radiocarbon dated to 2325–1460 BCE, confirming their Harappan context. Despite the surface disturbance and the limitation of faunal remains collected only through exploration, the systematic full-coverage survey helped accurately date and classify the artifacts, linking them to Harappan and regional Chalcolithic cultures in Gujarat. The collected artifacts and faunal remains have been studied to understand the cultural activities at the site (Gadekar et al., 2014; Patel et al., 2014; Rajesh et al., 2015; Ajith et al., 2019; Abhayan et al., 2024b) (Table 1).

4.5 Kotada bhadli

Kotada Bhadli (23° 20′ 45.6′′ N; 69° 25′ 33.6′′ E), located in the Nakhatrana Taluka of Kachchh district, Gujarat, was first identified by J.P. Joshi in 1965-66. His initial findings included Harappan ceramics and chert blades (IAR 1965-66, 1973). The site, covering approximately 1.2 hectares, is situated at the confluence of two rivers, making it a strategic location during the Harappan period. Excavations conducted between 2010 and 2013 by the Deccan College, Pune, in collaboration with the Gujarat State Department of Archaeology, uncovered key features, including a multi-roomed residential structure at the center of the site, surrounded by a fortification wall. The artifacts unearthed, such as typical Mature Harappan and regional Sorath Harappan ceramics, along with spherical weights, terracotta beads, and the construction style of the structures, indicate that Kotada Bhadli belonged to the Late Mature Harappan period. Based on these findings, the excavators (Shirvalkar and Rawat, 2012) have dated the site to between 2300 BCE and 2100 BCE. The faunal remains from Kotada Bhadli were studied by Pankaj Goyal (Goyal et al., 2018) (Table 1).

Several domestic mammals were identified from different occupational phases at the above sites, with cattle (*Bos indicus*) being the most dominant species. Other domestic animals include buffalo (*Bubalus bubalis*), goat (*Capra hircus*), sheep (*Ovis aries*), pig (*Sus domesticus*), dog (*Canis familiaris*), and cat (*Felis catus*). Additionally, the faunal assemblages contain a variety of wild mammals of small, medium, and large sizes, including nilgai, deer (sambar, spotted deer, barking deer, and mouse deer), antelopes (blackbuck, chinkara, and four-horned antelope), wild pig, wild ass, elephant, porcupine, mongoose, hare, hedgehog, and rhesus monkey. A range of carnivores, such as wolf, cheetah (?), panther, fox, desert cat, jungle cat, and small Indian civet, were also identified, along with reptiles and birds (Thomas et al., 1995; Chase, 2007, 2010, 2014; Joglekar and Goyal, 2011; Ajith et al., 2019; Goyal, 2021; Abhayan et al., 2024b).

5 Results and discussion

A detailed analysis of fish remains from Bagasra, Kanmer, and Shikarpur has resulted in a substantial increase in the number of identified fish remains within the overall assemblages. More samples were identified in this later analysis, significantly improving the taxonomic identifications compared to the cursory observations made during previous faunal studies (Chase, 2007, 2014; Joglekar and Goyal, 2011; Goyal, 2021). In the previous analysis, the total number of fish remains from Bagasra was 3,391, which has now increased to 8,232 in the current analysis. Similarly, the numbers for Kanmer have risen from 1,054 to 1,220, and for Shikarpur from 324 to 584. The quantity of samples from Navinal and Kotada Bhadli remains consistent with earlier studies (Goyal et al., 2018; Ajith et al., 2019) (Table 2).

TABLE 2 Summary of non-fish faunal identification and fish faunal identifications done by faunal and fish faunal analysts, respectively (Chase, 2007, 2014; Goyal, 2021; Goyal et al., 2018; Ajith et al., 2019).

	KMR I	BSR I+II+III	KMR IIA+IIB	SKP I+II	NVL	KTB	BSR IV	KMR III	SKP III	Total
Mammals and other non-fish fauna	831	23,611	16,203	20,729	1,221	19,348	2,007	4,447	1,583	89,980
Crab	-	492	-	186	35	-	21	-	-	734
Mollusk*	2	-	189	-	4,165	77	-	153	-	4,586
Fish (as recorded by faunal analysts)	4	2,580	602	322	2,357	91	811	448	2	7,217
Fish (as recorded by fish faunal analyst)	125	5,740	553	573	2,357	91	2,492	542	11	12,484

*Mollusk samples were not included in the analyses of Bagasra and Shikarpur.

5.1 Fish taxa identification

A total of 5,839 fish skeletal elements were identified to taxonomic categories from the analysis of 12,484 fish bone fragments, which were gathered from five selected sites. The percentage of total NISP is 46.77 % (Table 3). The identified assemblage represents members of a total of 14 fish families, including Ariidae, Bagridae, Carangidae, Latidae, Carcharhinidae, Dasyatidae, Cyprinidae, Haemulidae, Platycephalidae, Polynemidae, Sciaenidae, Serranidae, Siluridae and Sparidae (Table 4, Figures 3, 4).

Lates calcarifer (Figure 5) is the most dominant single species of fish in the assemblages except for Navinal which is a different kind of assemblage dominated by fish otoliths sourced from the contexts with possible differential preservation conditions. The otoliths are dominantly represented at Navinal, which belongs to mostly the Ariidae, and Sciaenidae families. The Ariidae family is represented next in the order of abundance consisting of different species such as *Arius arius, Arius maculatus, Arius subrostratus, Netuma thalassina* and *Plicofollis layardi* (Figure 6). *Mystus* cf. *gulio* and members of the Bagridae family (Figure 7) are represented in relatively large numbers next to that.

The members of the Sciaenidae family (Drums/Croakers) such as *Argyrosomus japonicus, Daysciaena albida, Johnius belangerii, Otolithes cuvieri, Otolithes ruber, Otolithoides biauritus,* and *Nibea maculata* and Chondrichthyes like Requiem Sharks/Sting Rays are represented in considerable numbers across the sites. The fish taxa that occur in lesser quantities include the Seabreams such as *Acanthopagrus berda* (Sparidae family), Grunts such as *Pomadasys argenteus* (Haemulidae family), Groupers like *Epinephelus* sp. (Serranidae family), Queenfish like *Scomberoides* sp. (Carangidae family), Threadfins like *Eleutheronema tetradactylum* (Polynemidae family), Flatheads like *Grammoplites* sp. (Playcephalidae family), Freshwater Catfish/*Wallago attu* (Siluridae family), Rohu/*Labeo rohita* (Cyprinidae family) (Figures 3, 4, 7).

The Ariidae family was present in smaller quantities at Kanmer compared to Bagasra, Shikarpur, and Navinal, where they were found in greater abundance. Additionally, a notable aspect is that the Ariidae bones recovered from nearly all phases at Kanmer belonged to relatively small-sized fish. In contrast, larger Ariidae species, such as *Netuma thalassina*, were identified at Bagasra in higher numbers. The absence of larger Ariidae fish and the lower quantity of Ariidae remains at Kanmer is striking, especially when compared to the fish assemblages at nearby sites like Bagasra (Abhayan et al., 2018), Shikarpur (Abhayan et al., 2024a) and Navinal (Abhayan et al., 2016) (Table 4).

The fishbone remains from sites in the Gulf of Kachchh region such as Bagasra, Kanmer, and Shikarpur show a predominant presence of *Lates calcarifer* (Abhayan, 2016). This pattern contrasts with the fish remains from the Harappan period in the coastal region of Karachi, Pakistan, which includes sites like Balakot and Allahdino, where the fish remains are dominated by *Pomadasys argenteus* (cf. *Pomadasys hasta*) (Belcher, 1998, 2000, 2005) (Figure 1). Despite both regions being coastal, and not very distant, the differences in dominant fish species reflect the region-specific availability of fish. These findings from the archaeological record closely mirror the modern-day fishing practices and fish landings in these areas revealed through ethnographic surveys, where similar species distribution patterns are observed (Belcher, 1999; Abhayan and Rajesh, in preparation)[1]. The overall composition of other fish species found in archaeological contexts in both regions does not show significant variation. Apart from the exploitation of these two region-specific fish species by the coastal communities, the relatively uniform representation of other fish species suggests a shared aquatic adaptation in both regions.

5.2 Temporal variations

The fish faunal data does not represent the Early Harappan Phase, except for Kanmer, where only a small uncertain sample set is available and matches with the KMR IIA phase. All five sites represent fish remains from the Mature Harappan Phase, characterized by their substantial presence, indicating marine-estuarine fishing practices. The Late Harappan Phase is represented by fish remains from Bagasra and Shikarpur, with the Late Mature Harappan phase of Kanmer showing significant shifts. Therefore, meaningful discussions can be made primarily regarding the Mature Harappan and Late Harappan phases.

Lates calcarifer and members of the Ariidae family consistently dominate the assemblages from Bagasra, Kanmer, and Shikarpur

1 Abhayan, G. S., and Rajesh, S. V. (in preparation). Ethnoarchaeological perspectives on fishing around the Harappan site of Navinal, Gujarat. *J. Multidiscip. Stud. Archaeol.*

TABLE 3 Summary of fish identification from Bagasra, Kanmer, Shikarpur, Navinal, and Kotada Bhadli.

Id. Summary	KMR I	BSR I+II+III	KMR IIA+IIB	SKP I+II	NVL	KTB	BSR IV	KMR III	SKP III	Total
Total fragments	125	5,740	553	573	2,357	91	2,492	542	11	12,484
NISP	36	1,924	228	240	2,354	25	837	188	7	5,839
Teleostei indet.	89	3,816	325	333	3	66	1,655	354	4	6,645

across all phases. Even with the small sample set from Kotada Bhadli, this pattern is observable.

The Bagridae family, specifically *Mystus* cf. *gulio* is another noteworthy group, particularly due to its relative abundance in the Late Harappan context at Bagasra and Late Mature Harappan context at Kanmer (Abhayan et al., 2018, 2020). While Bagridae were present throughout the phases, their quantity increased during the Late Mature Harappan and Late Harappan Phases. This significant increase in Bagridae bones suggests a greater exploitation of freshwater environments or interior water bodies with lower salinity (Table 4, Figure 3). To test the null hypothesis of random interaction between the occurrence of Bagridae against other remains and the Harappan phases, a Chi-square test was performed on log-transformed values (to take care of large and uneven sample numbers). The test showed that the null hypothesis of randomness on the association is rejected (Chi-square value = 3.98, significant at Alpha = 0.05). Thus, the test supports that there was a statistically significant increase during the later Harappan phases.

The increase in Bagridae during the later Harappan periods may be attributed to several factors. Environmental changes likely altered local aquatic ecosystems, favoring freshwater species such as Bagridae. Cultural shifts in fish consumption preferences among the Harappans could have also influenced this trend. Furthermore, a decline in infrastructure and expertise related to marine fishing may have resulted in a greater reliance on freshwater resources. Additionally, the emergence of small-scale fishing practices by a possible parallel group of fishermen may have contributed to the increased exploitation of Bagridae during this period. However, this pattern is primarily reflected in data from two sites with reliable sample sets, while other sites under consideration lack sufficient Late Harappan samples. Further investigation, involving a broader analysis of fish remains from excavated contexts that maintain proper stratigraphic control, is necessary to confirm the above observations.

5.3 Fishing environments

Knowing the taxonomic position of the fish bone assemblages provided valuable information about the habitats of specific fish species, which allows us to assume the likely fishing locations. The identified fish species from the assemblages (Table 4) suggest that the majority of fish exploitation occurred in a marine environment. More specifically, fishing activities were concentrated around estuaries, creeks, and nearby coastal waters, extending to a maximum depth of ∼50 m. This suggests that fishermen did not venture far offshore to catch the fish species identified in the assemblage. Instead, they focused on relatively accessible, nearshore waters, likely rich in marine life. This pattern of fishing close to shore reflects a strategic use of local marine resources without the need for long-distance voyages into the open sea. Although these fish species, particularly larger sharks and marine catfish, typically inhabit deeper sea waters, they occasionally venture into estuarine mouths, connected creeks, and brackish waters, where they are likely to be caught.

The presence of freshwater fish such as *Mystus* cf. *gulio* (Long Whiskers Catfish), *Wallago attu* (Freshwater catfish), *Labeo rohita* (Rohu), and *Rita rita* (Rita Catfish) suggests that freshwater fishery was in existence alongside marine. Freshwater catfish, Rohu, and Rita Catfish primarily inhabit large freshwater bodies such as rivers and lakes, though they can tolerate brackish waters to some extent. Similarly, the members of the Bagridae are mostly found in freshwater environments but enter slightly brackish or saline waters. *Mystus* cf. *gulio* typically prefers freshwater or brackish water, especially in larger water bodies like rivers and creeks with mud or clay substrates. In comparison to other reported marine-estuarine fish species in the assemblages, *Mystus* cf. *gulio* generally inhabits less-saline waters (Breder and Rosen, 1966; Iqbal et al., 2024).

Extensive fishing practices, possibly on a large scale, were conducted across various environments, including freshwater systems, estuaries, and coastal regions in the Gulf of Kachchh, as indicated by the diversity of fish species. These fishing activities likely involved specialized groups who employed specific techniques suited to each environment. For instance, marine fishing may have been influenced by tidal patterns, much like contemporary practices observed in the Gulf of Kachchh (Patel, 2019). However, linking a particular fish species to a specific fishing technique is not always straightforward. This is because multiple techniques can be used to catch the same species (Colley, 1990; Belcher, 1998). The artifact inventory from the selected sites lacks direct evidence of fishing equipment, such as fishhooks and harpoons, which have been found at other Harappan sites (e.g., the copper fish hooks from Lothal and Padri) (Rao, 1985; Shinde and Thomas, 1993). Nevertheless, some objects, such as grounded and notched shell columellae, terracotta beads, and perforated pottery discs, might have functioned as net sinkers, and pottery paintings with lattice patterns hint at the possible use of fish traps or nets (Endo et al., 2012; Uesugi and Meena, 2012; Ruikar, 2013). Artifacts and contextual evidence from archaeological sites are crucial for understanding ancient fishing gears and techniques, as well as for reconstructing the organizational systems that supported these complex and regionally adaptive practices (Abhayan et al., 2020).

It is beneficial to examine the accessibility of the selected sites to water sources to understand their environmental context concerning fishing activities. Except for Kotada Bhadli, the other

TABLE 4 NISP and MNI of fish remains from Bagasra, Kanmer, Shikarpur, Navinal, and Kotada Bhadli.

Taxa	English Common Name	KMR I		BSR I+II+III		KMR IIA+IIB		SKP I+II		NVL		KTB		BSR IV		KMR III		SKP III		Total	Total
		NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI
Sparidae/Latidae indet.	Porgy/Lates Perch	4	1	26	2	18	2	2	2					6	1	19	1			75	9
Lates calcarifer	Barramundi	27	11	533	78	148	30	102	13			2	1	132	27	102	12	4	1	1,050	173
Sparidae indet.	Porgy			39	16									9	2					48	18
Acanthopagrus berda	Goldsilk Seabream			31	11			2	1			1	1	3	1					37	14
Sciaenidae indet.	Drum and Croaker			110	20	1	1	25	5	103	74			61	13	1	1			301	114
Argyrosomus japonicus	Japanese Meager							1	1											1	1
Daysciaena albida	Bengal Corvina			12	6					27	19			1	1					40	26
Johnius belangerii	Belanger's Croaker			5	4					3	3									8	7
Otolithes sp.	Tigertooth Croaker			7	5			1	1					15	8					23	14
Otolithes cuvieri	Lesser Tigertooth Croaker			12	9									2	1					14	10
Otolithes ruber	Tigertooth Croaker			9	5					10	8			2	1					21	14
Otolithoides biauritus	Bronze Croaker			2	1			1	1	19	16			4	4					26	22
Nibea maculata	Blotched Croaker							1	1											1	1
Haemulidae indet.	Grunts													1	1					1	1
Pomadasys argenteus	Silver Grunt			2	1									2	1	1	1			5	3
Epinephelus sp.	Grouper			9	3															9	3
Scomberoides sp.	Queenfish			1	1															1	1
Eleutheronema tetradactylum	Fourfinger Threadfin													24	9					24	9

(Continued)

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TABLE 4 (Continued)

Taxa	English Common Name	KMR I		BSR I+II+III		KMR IIA+IIB		SKP I+II		NVL		KTB		BSR IV		KMR III		SKP III		Total	Total
		NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI
Grammoplites sp.	Flathead			2	2															2	2
Siluriformes indet.	Catfish			75	2	3	2	7	2					10	1	3	1			98	8
Ariidae/Bagridae indet.	Sea Catfish/Bagrid Catfish			163	6	11	3	2	1					64	15	7	1			247	26
Ariidae indet.	Sea Catfish			341	14	8	3	17	3	408	309	1	1	75	1	1	1			851	332
Arius arius	Threadfin Sea Catfish			5	1															5	1
Arius maculatus	Spotted Catfish			60	18	1	1	7	2	1,658	1,023			33	7	1	1			1,760	1,052
Arius subrostratus	Shovelnose Sea Catfish			2	2															2	2
Netuma thalassina	Giant Catfish			267	48	1	1	51	4	29	20			88	8			2	1	438	82
Plicofollis layardi	Thinspine Sea Catfish			1	1															1	1
Bagridae indet.	Bagrid Catfish	3	2	10	2	6	2					2	1	252	86	20	8			293	101
Mystus cf. *gulio*	Long Whiskers Catfish	2	2	40	13	20	11	3	2					43	1	32	14			140	43
Rita rita	Rita Catfish							1	1											1	1
Wallago attu	Wallago Catfish			13	4	8	1	7	2			2	1	1	1			1	1	32	10
Labeo rohita	Rohu			1	1	2	2							1	1					4	4
Carcharhinidae/ Dasyatidae	Requiem Sharks/ Sting Rays			146	2	1	1	10	2	97	1	6	1	8	1	1	1			269	9
Teleostei indet.	Bony fish Unidentified	89		3,816		325		333		3		77		1,655		354		4		6,656	
Total		125	16	5,740	278	553	60	573	44	2,357	1,473	91	6	2,492	192	542	42	11	3	12,484	2,114

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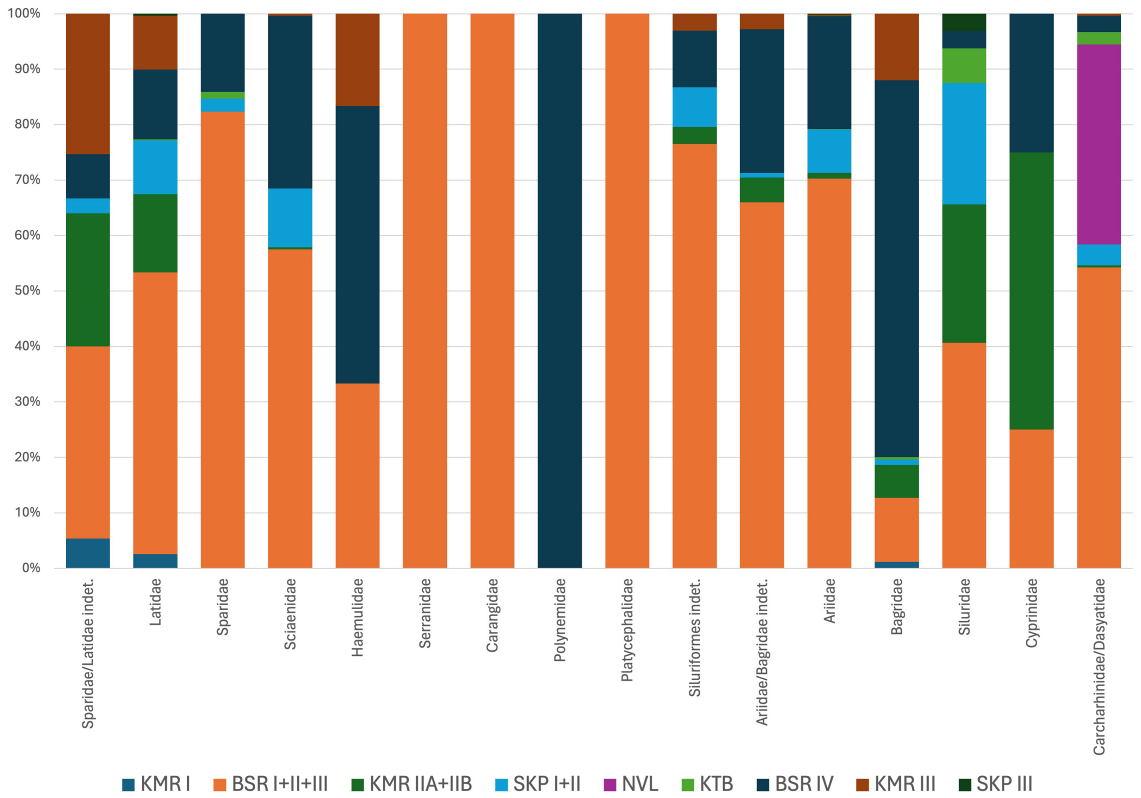

FIGURE 3
Combined fish taxa representation from Bagasra, Kanmer, Shikarpur, Navinal, and Kotada Bhadli, exempting Otoliths from Navinal and all Teleostei indet.

four sites are situated close to the Rann of Kachchh or the coastal area, which is characterized by an estuarine environment. At Kanmer, the nearest natural freshwater source is a seasonal stream called Aludawaro Vokro, which flows from hillocks about 2 km northwest of the site. Additionally, a large freshwater reservoir lies to the west. Satellite imagery indicates that the fringe of the Little Rann of Kachchh was once located ∼1.5 km southeast of Kanmer, although the modern seashore is now about 5 km away (Kharakwal et al., 2012a,b). Bagasra is situated about a kilometer from a creek that extends from the Gulf of Kachchh (Sonawane et al., 2003). Similarly, Shikarpur is located at the edge of a narrow creek that flows eastward from the Gulf of Kachchh (Bhan and Ajithprasad, 2009).

The landscape surrounding Navinal has undergone significant alteration in recent times, making it challenging to identify smaller water sources and their distribution in the immediate vicinity. However, the distance from Navinal to the nearest creek connected to the coast is less than 1 km to the south, with the coast itself located ∼5 km away (Ajith et al., 2019). Kotada Bhadli is uniquely positioned at the confluence of two seasonal rivers (Shirvalkar and Rawat, 2012).

To comment on the general Harappan regime and its environments in the Kachchh region, several studies support the notion that the hydrological characteristics were more favorable during the peak of the Harappan occupation. Scientific methods, including palaeobotanical (Pokharia et al., 2011), anthracological (Lancelotti and Madella, 2011), geological (Singhvi and Kale, 2009; Deo et al., 2011), and stable isotopic analyses (Amekawa et al., 2016; Sengupta et al., 2020), have provided evidence for better hydrological conditions.

5.4 Spatial distribution

During Phases II and III at Bagasra and Phases I and II at Shikarpur, variations in fish utilization between areas inside and outside the fortifications are evident. These phases represent two Urban periods within the Mature Harappan Phase at both sites (Table 1). In the earlier phases, the inhabitants both inside and outside the walls appear to have consumed marine and large freshwater fish in nearly equal quantities. However, in the subsequent phases, those living outside the walls seem to have had reduced access to both marine fish and large freshwater species, while the occupants within the walls continued to enjoy marine fish. This shift may be attributed to a general economic decline among the external settlers, likely making it difficult for them to afford the more expensive marine fish during the later part of the Urban Phase. The increased frequency of larger marine fish species, such as *Netuma thalassina*, found within the fortified areas suggests that the highest quality marine catch was reserved for the inhabitants of these zones (Figures 8, 9).

Similarly, during Phase I at Shikarpur, larger freshwater species like *Rita rita* and *Wallago attu* were also found more frequently inside the fortification. Marine fishery had significant

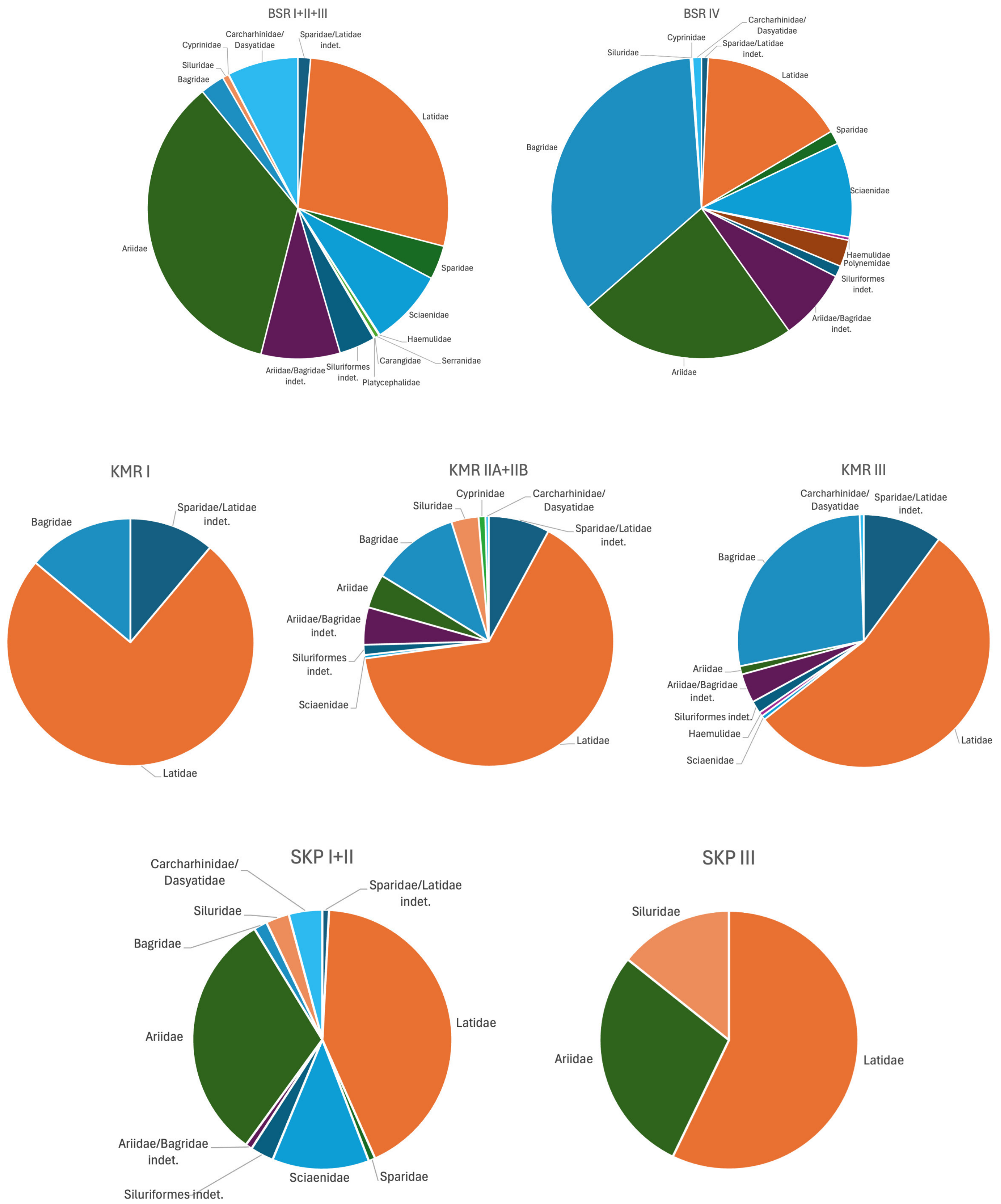

FIGURE 4
Phase-wise fish taxa representation from Bagasra, Kanmer, Shikarpur.

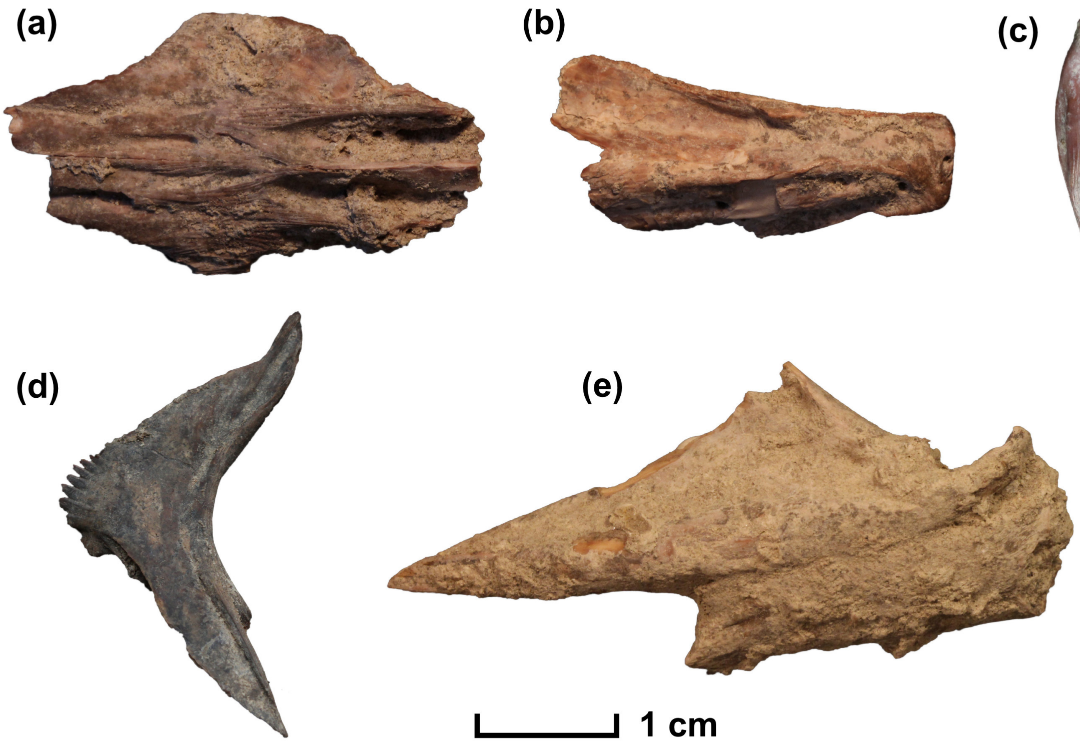

FIGURE 5
Bones of *Lates calcarifer*. **(A)** Cranial fragment, Shikarpur, **(B)** Dentary, Shikarpur, **(C)** Supraclavicle, Kanmer, **(D)** Cleithrum, Kanmer, **(E)** Articular, Bagasra.

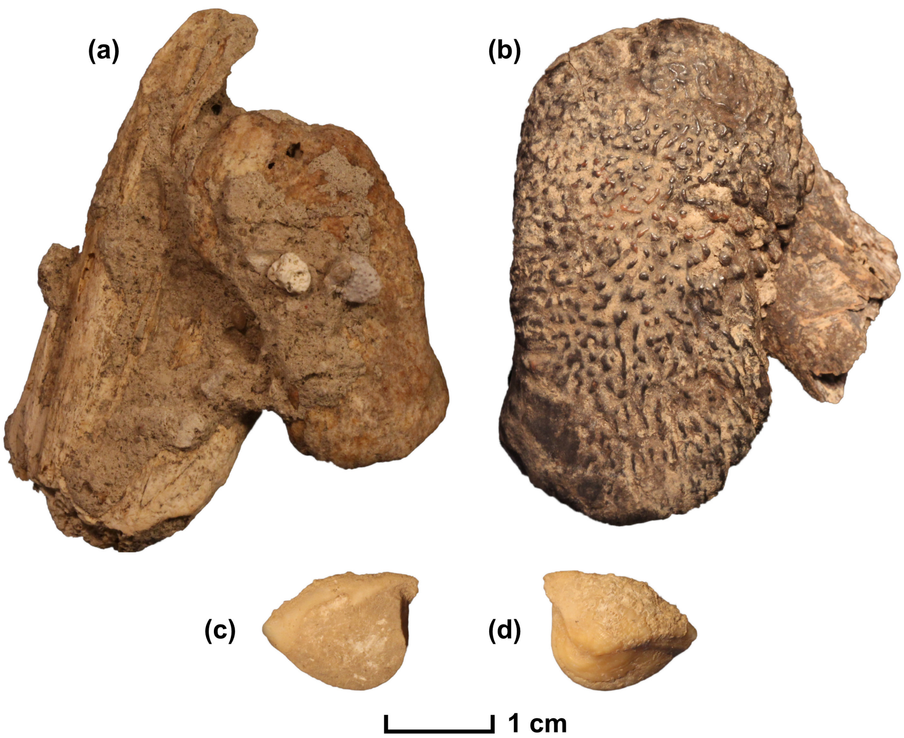

FIGURE 6
Bones of Ariidae. **(A, B)** Ethmoid cornu portions of cranium of *Netuma thalassina*, Bagasra, **(C, D)** Lateral and medial views of Ototlith of *Netuma thalassina*.

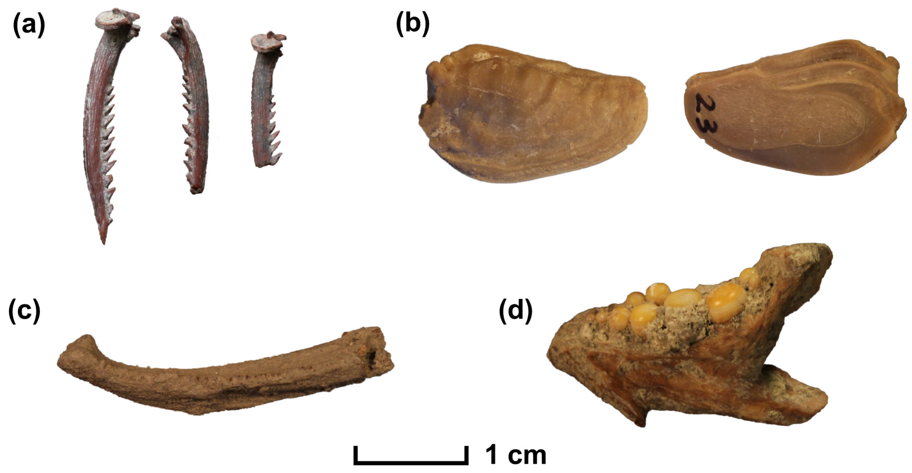

FIGURE 7
(A) Pectoral Spines of *Mystus* cf. *gulio*, **(B)** Lateral and medial views of Otolith of *Otolithoides biauritus*, **(C)** Dentary of *Grammoplites* sp., **(D)** Dentary of *Acanthopagrus berda*.

demand during the Urban Harappan Phases and may have been a specialized occupation, requiring advanced infrastructure and fishing equipment. This suggests that there was societal demand for specific fish species, with a likely higher demand for marine fish. Marine fish products may have been consumed more by the affluent urban population living within the fortified areas, indicating that fish was an important dietary component for the socially privileged during this period (Abhayan et al., 2018). Differences in consumption patterns between the inhabitants inside and outside the fortification are also evident in the mammalian faunal records from Bagasra and Shikarpur (Chase, 2010, 2014). The inside settlers consumed more mutton than beef compared to those outside the fortification. Moreover, the inside settlers controlled craft manufacturing activities (Sonawane et al., 2003). This evidence highlights the presence of a social or economic hierarchy between the inhabitants within the settlement and those outside.

Another piece of evidence from Kotada Bhadli is the identification of marine fishbones, including those of sharks (Charcharinidae), Barramundi (*Lates calcarifer*), and Sea Catfish (Ariidae) (Table 4). Notably, this site is located in the interior of the Kachchh mainland, ~50 kms from the coastal fringe. The presence of marine species at such a distance from the sea strongly suggests the long-distance transportation of fish for consumption at Kotada Bhadli. The fortified settlement of Kotada Bhadli has been proposed as a traders' emporium (Caravanserai), serving as a resting point along trade networks that traversed the Kachchh region (Shirvalkar and Rawat, 2012; Shirvalkar, 2023). In this context, marine fish were likely transported through these trade routes from coastal settlements. The demand for marine fish at Kotada Bhadli could have been driven by the dietary preferences of the settlers or the traders passing through the area.

This pattern of long-distance fish transportation is paralleled at Harappa, where marine fish species have also been discovered, despite the site being ~800 kms inland from the coast of present-day Pakistan (Belcher, 1998). This suggests that the transport and consumption of marine fish at inland sites may have been a widespread practice in ancient trade networks across the Harappan regimes.

5.5 Skeletal frequency

In comparison to the lower cranial bones, the number of vertebral elements is relatively lower with respect to their proportionate numbers in the fish anatomy. Similarly, the quantities of spines (pectoral and dorsal), ribs, and pterygiophores are also relatively lower. This suggests that the fish were fileted, and the vertebral portions, along with other fin-bearing bones, were discarded before the fish was brought to the settlement for consumption (Table 5).

Pectoral bone elements, particularly the cleithra, are represented in larger numbers compared to lower cranial bones, especially the bones like preoperculum, dentary, articular, premaxilla, maxilla, post-temporal, quadrate, and supraclavicle. The lower cranial bones of fish, especially those of *Lates calcarifer*, are as dense and ossified as the cleithrum. Therefore, if the cleithrum has been preserved, the lower cranial bones should have been preserved as well, ruling out the possibility of differential bone preservation in this context. This indicates that, relative to the cleithrum, a proportionate number of lower cranial bones did not reach the site. Furthermore, these lower cranial elements, especially preoperculum, dentary, articular, premaxilla, and maxilla, are highly diagnostic, minimizing the chances of misidentification or recovery bias. This pattern of bone representation can be interpreted as a specific method of fish processing, where the gut and lower cranial bones were removed from the anterior portion of the opercular cleft while retaining the cleithra with the fish filet. Such processing patterns are evident in the assemblages from Bagasra, Kanmer, and Shikarpur, suggesting similar fish processing and distribution practices across the region (Table 5, Figure 10).

Likewise, neurocranial fragments are represented in lower numbers relative to their anatomically proportionate quantities. This suggests that the fish heads were likely severed using tools

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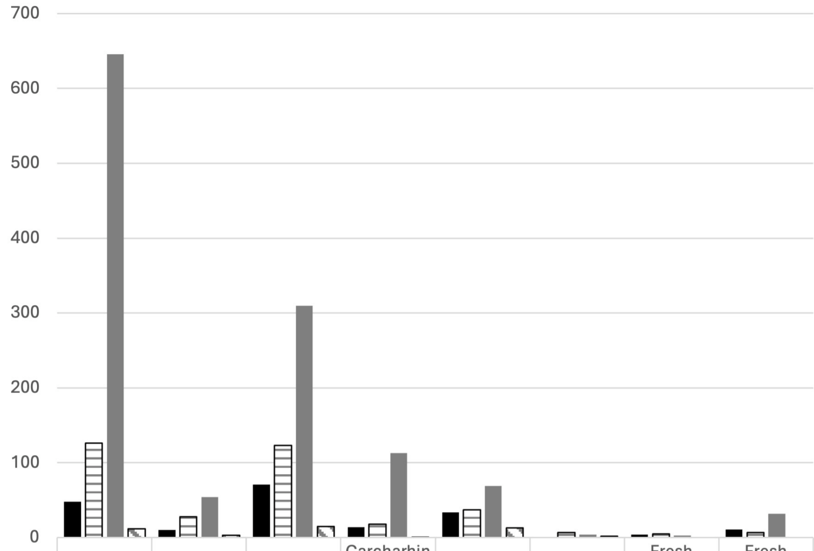
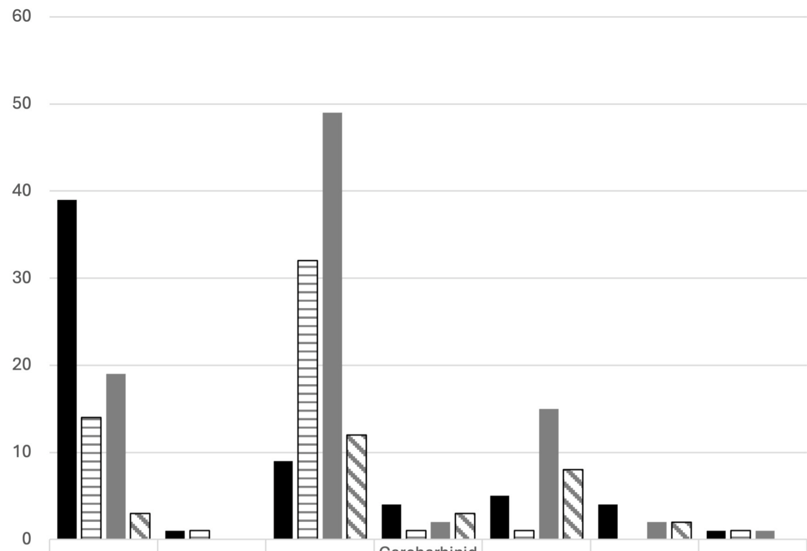


	Ariidae	Sparidae	Lates calcarifer	Carcharhinidae/ Dasyatidae	Sciaenidae	Other Marine	Fresh water (Large)	Fresh water (small)
Inside-BSR II	48	10	71	14	34		4	11
Outside-BSR II	126	28	123	18	37	7	5	7
Inside-BSR III	646	54	310	113	69	4	3	32
Outside-BSR III	12	3	15	1	13	2		

FIGURE 8
Fish taxa representation inside and outside of the fortified area of Bagasra during Phases II and III.



	Ariidae	Sparidae	Lates calcarifer	Carcharhinidae/ Dasyatidae	Sciaenidae	Fresh water (Large)	Fresh water (small)
Inside-SKP I	39	1	9	4	5	4	1
Outside-SKP I	14	1	32	1	1		1
Inside-SKP II	19		49	2	15	2	1
Outside-SKP II	3		12	3	8	2	

FIGURE 9
Fish taxa representation inside and outside of the fortified area of Shikarpur during Phases I and II.

TABLE 5 Skeletal elements distribution from Bagasra, Kanmer, Shikarpur, Navinal, and Kotada Bhadli.

Bone elements	KMR I	BSR I+II+III	KMR IIA+IIB	SKP I+II	NVL	KTB	BSR IV	KMR III	SKP III	Total
Angular	1									1
Articular	1	103	6	16			39	7		172
Basioccipital		18	1				10	2		31
Basipterygium		7	1				1			9
Branchiostegal Rays		16								16
Ceratohyal		10		2			2			14
Cleithrum	18	449	81	51		1	166	39	1	806
Cleithrum+Pectoral Spine	1	16	4				192	10		223
Cranium		469	6	55			160	4		694
Cranium+Vomer		1								1
Dentary	1	138	7	11			38	8	2	205
Dentary+Articular		7								7
Dorsal Spine	5	83	49	16		1	36	31	2	223
Epihyal		4	2	2			2			10
Epihyal+Ceratohyal		7		1			5			13
Epibranchial		0					1			1
Fish Bone indet.	14	940	26	112		66	670	32		1,860
Fin Rays	1	183	15	10			143	29		381
Gill rakers		1								1
Hypohyal		0		1			2			3
Hyal		5	1	4						10
Hyomandibular		16		4			7		1	28
Hypural		45	4	1			30	2		82
Maxilla		72	1	19			42	6		140
Modified First Dorsal Spine		4					3			7
Operculum		40	1	10			15			66
Opercular (general)		9	1	1			5	1		17
Otolith		86		17	2,257		45		1	2,406
Parasphenoid		8	1	3			4	1		17
Pelvic Girdle			1							1
Pectoral Girdle		0					1			1
Pectoral Spine	2	91	24	6			29	33		185
Pharyngeal	1	5		1			4			11
Post-temporal		12	3				3	1		19
Premaxilla		87	1	13			48	1	1	151
Premaxilla +Maxilla		2								2
Preoperculum		79	14	10			23	16		142
Pterygiophore	11	167	21	6			27	36		268
Quadrate		50	1	9			15	5		80
Ribs		26	2					8		36
Ribs/Branchiostegal Rays	6	236	1	54			81			378

(Continued)

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TABLE 5 (Continued)

Bone elements	KMR I	BSR I+II+III	KMR IIA+IIB	SKP I+II	NVL	KTB	BSR IV	KMR III	SKP III	Total
Spine (general)	43	816	121	26		10	135	137	2	1,290
Spine/Branchiostegal Rays		2					5			7
Supraclavicle	1	16	2	5		1	2	8		35
Tooth		1								1
Urohyal		0	1				5	1		7
Vertebrae	19	1,403	154	107	100	12	492	124	1	2,412
Vertebrae+Hypural		0					1			1
Vomer		10					3			13
Total	125	5,740	553	573	2,357	91	2,492	542	11	12,484

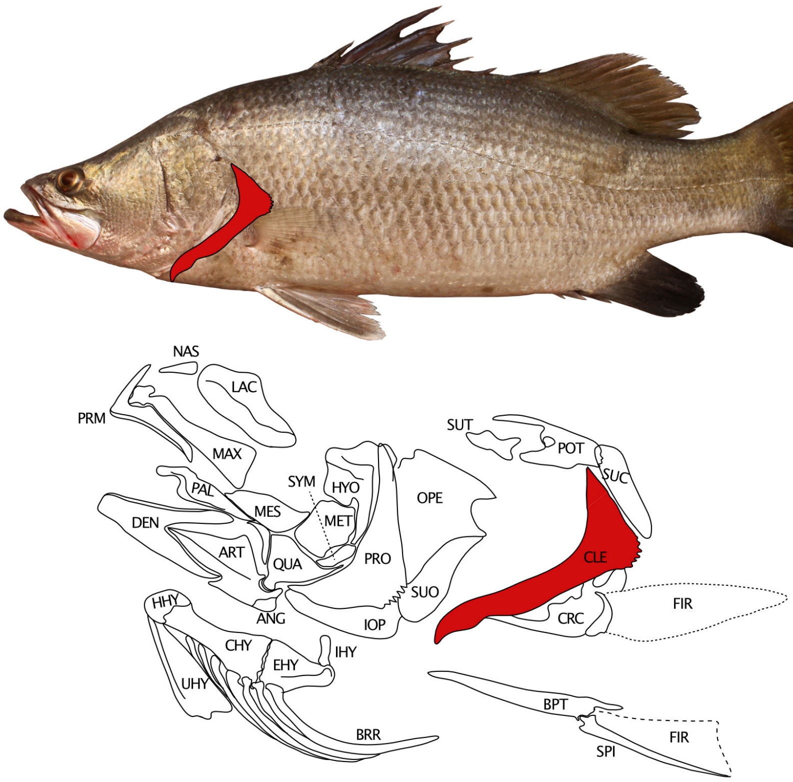

FIGURE 10
Diagram showing the anatomical position of the cleithrum in *Lates calcarifer* and an illustration of the major lower cranial bones in their respective anatomical positions.

rather than processed by hand. If the fish heads had been processed by bare hand, the neurocranial elements would have remained with the rest of the fish and would have been recovered in higher numbers, possibly equal to or exceeding that of the cleithra. Supporting this hypothesis, cut marks have been observed on many cranial elements (discussed in the section below). This evidence points to the possibility that the fish were processed somewhere else outside the site or landing site before being brought to the settlement. This pattern of processing appears to apply to most fish species, except for catfish. For catfish, such as those from the families Ariidae and Bagridae, the cranial elements are represented in relatively higher numbers, suggesting a different processing method. However, whole fish were occasionally brought to the settlements for consumption, as indicated by the presence of nearly all skeletal elements of fish in the assemblages. No significant or diagnostic skeletal elements were entirely absent, reinforcing the idea that whole fish were sometimes brought to the site for direct use.

If the fish were not transported in fresh form, they were likely preserved by sun-drying or salting for later use. Additionally, the large quantities of *Lates calcarifer* in the assemblage suggest a surplus catch, making this species ideal for storage. The Harappans in inland regions were familiar with marine fish, as evidenced by fish bone finds at Kotada Bhadli (Table 4), and Harappa (Belcher, 1998). The occurrence of marine fish at these distant locations further supports the notion of fish being processed for storage and transportation.

While Bagasra and Shikarpur exhibit the presence of a few otoliths, Navinal shows a large number of otoliths from both Ariidae and Sciaenidae, with relatively few vertebral bones (Tables 4, 5). The reasons for their abundance at this site are unclear. This could be interpreted as the result of differential preservation, a specific method of fish processing, or a cultural practice leading to their separation.

5.6 Bone modifications

A total of 390 fish bone fragments from Bagasra, Kanmer, Shikarpur, and Navinal exhibit various forms of bone modifications (Table 6). These modifications include cut marks, burnt marks, evidence of human chewing and crushing, scavenging by carnivorous animals, as well as alterations to ornaments and tools. The cut marks were categorized based on the force applied and the characteristics of the cut surfaces, with classifications including shallow, deep, chopping, multiple cuts, and blunt cuts. Similarly, different degrees of burning and charring were observed, ranging from completely black or white to partially black or white. More evidence of modification would likely have been recorded if the bones had not been obscured by salt encrustations and soil particles, as observed on most of the samples.

Charring is the most frequently observed form of bone modification, accounting for 247 fragments, with the majority (216 fragments) coming from Bagasra. A total of 18 otoliths and one vertebral element from Navinal were found to be charred. Various degrees of charring were observed, with most of the charred bones being completely blackened (Figure 11). However, charred marks may indicate the practice of roasting fish for consumption. Alternatively, some of these marks could result from accidental burning, possibly during waste disposal or other similar activities.

In contrast to the dominance of charring at other sites, cut marks are more prevalent at Kanmer, with 20 fragments showing evidence of cuts. A total of 132 fragments in the assemblages showed cut marks, which were categorized into five types. Most cut marks are classified as deep or shallow cuts, while chopped bone surfaces were identified on 21 fragments. Multiple occurrences of cuts were recorded on 9 fragments, and blunt cuts on 6 (Figure 11). The tools used to make these cuts are not discernible from the marks, but they may have included copper knives or composite tools with lithic components, as suggested by the artifact inventory from these sites.

One vertebra each from Bagasra and Kanmer exhibits a crushed appearance, likely resulting from human chewing. Another vertebra, with ground edges on the centrum, may have been used as an ornament, such as an ear pendant. Similar modified vertebrae are used as ear pendants by contemporary ethnic communities (Abhayan and Rajesh, in preparation) (see text footnote[1]). Additionally, a vertebra from a shark was found with an intentionally made perforation through the centrum (Figure 11), suggesting it may have been used as a bead or pendant. Four fragments from Bagasra showed evidence of animal scavenging, likely caused by small felids or rodents. Although scavenging evidence was found in small numbers, it provides an important indication of the potential disappearance of a significant portion of fish bones due to this factor. Moreover, one dorsal spine was found with sliced lateral edges, indicating an attempt at shaping, possibly for use as a small pick or to be hafted as an arrowhead (Figure 11).

The distribution of cut marks across different skeletal elements reveals that the majority are found on neurocranial and vertebral elements (Figure 12), likely indicating fish processing at the market level (Belcher, 1995, 1998). This method of provisioning involved chopping off the fish's head, typically just anterior to the frontal or parietal part of the cranium. The higher frequency of cut marks on the cleithrum suggests the direction of the cut crossed both the cranium and the cleithrum. Additionally, cut marks on the vertebral column suggest that the fish was likely segmented into chunks during processing. However, it is difficult to interpret the complex fish processing patterns based solely on fish bone modifications, as many fish, particularly smaller species, do not leave any physical traces on their bones after processing and consumption (Colley, 1990).

5.7 Inter and intra-site comparison with Harappan subsistence strategies

Given the importance of pastoralism in the Harappan Civilization's animal-based subsistence, it is essential to compare the data on mammals with that of fish and other aquatic fauna for a nuanced understanding of the spectrum of animal-based subsistence in the region being discussed (Table 2).

The faunal assemblages across five sites consistently show a dominance of mammals, particularly cattle and sheep/goat, indicating the importance of their domestication. Both quantitative and qualitative analyses have been extensively conducted, establishing that pastoralism was integral to the society's existence. The studies on primary and secondary product utilization and provisioning of animal products have reinforced this understanding. Additionally, the exploitation of wild mammals and reptiles has also been documented (Chase, 2007, 2014; Ajith et al., 2019; Goyal, 2021).

Besides mammals, the utilization of fish, crabs, and mollusks was an essential component of the subsistence strategies. While crab remains were absent at Kanmer and Kotada Bhadli, they have been found in considerable quantities at the other three sites. Similarly, although mollusk remains were not included in the faunal samples studied at Bagasra and Shikarpur, these sites have reported large quantities of gastropod remains, primarily linked to craft manufacturing (Sonawane et al., 2003; Bhan and Ajithprasad, 2009; Ilahi et al., 2023).

At Bagasra, the inhabitants consistently relied on cattle and buffalo across four phases, with significant reliance on sheep and goats and minimal dependence on hunting wild mammals. Within the site, settlers inside the fortifications consumed more mutton than those outside, particularly in Phase II.

TABLE 6 Fishbone modifications from Bagasra, Kanmer, Shikarpur, and Navinal.

	KMR I	BSR I+II+III	KMR IIA+IIB	SKP I+II	NVL	BSR IV	KMR III	SKP III	Total
Cut mark (shallow)	1	15	4	5		18	6		49
Cut mark (deep)	1	32	3	3		6	2		47
Cut mark (chopping)		10		1		9	1		21
Cut marks (multiple)		5	2			2			9
Blunt cut		3				3			6
Burning (complete black)		123		4	8	9	3		147
Burning (complete white)		16		4		1			21
Burning (partially black)		33		1	11	22	1		68
Burning (partially white)		9				1	1		11
Crushed/human chewing	1					1			2
Scavenging		4							4
Ornament		3							3
Tool		1				1			2
Total	3	254	9	18	19	14	14		390

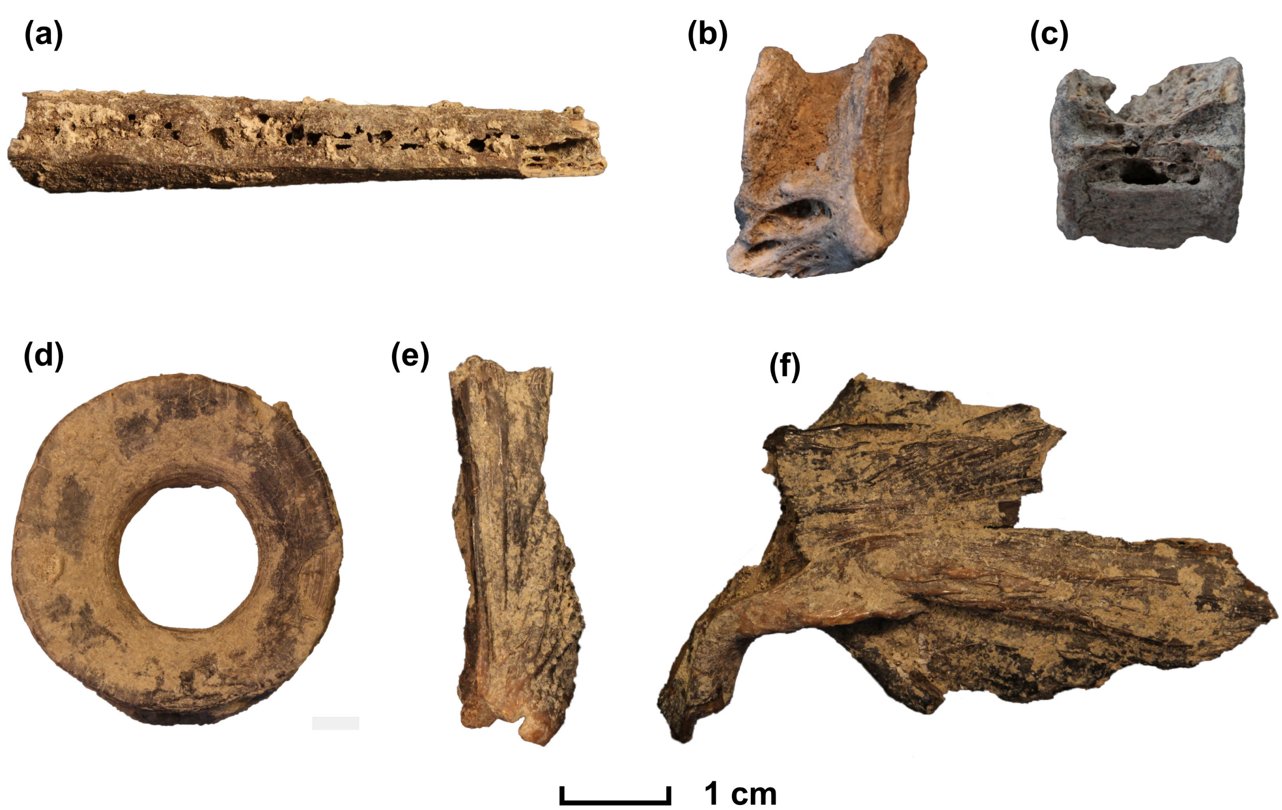

FIGURE 11
Bone modifications. **(A)** Fin spine with cut surface, Bagasra **(B)** Vertebra with a blunt cut, Shikarpur, **(C)** Vertebra with a deep cut, Kanmer, **(D)** Shark vertebra with evidence of intentional perforation, Bagasra, **(E, F)** Cranial fragments of Ariidae with burnt marks.

Seafood consumption at Bagasra increased during Phases II and III compared to Phase I. Residents inside the fortifications consumed more fish, while those living outside the fortified area ate more crabs. In the final phase, fish constituted a larger proportion of overall meat consumption than in the earlier phases (Chase, 2007). This indicates a distinct variation in preferences or access to aquatic resources between the two areas.

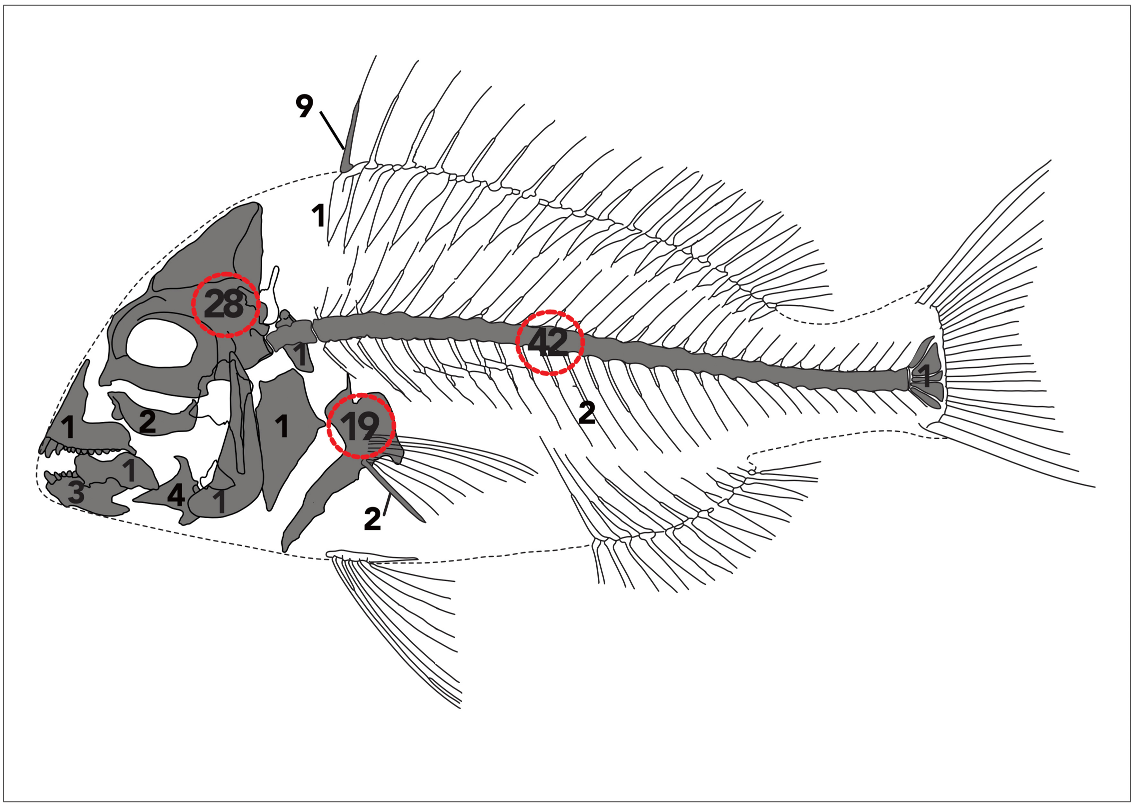

FIGURE 12
Illustration showing the distribution of cut marks on fish bones. The red dotted circle highlights areas with a higher concentration of cut-marked bones.

In KMR I, beef was the primary food source, with mutton and wild animals supplementing the diet. In KMR IIA, there was an increase in using cattle and sheep/goats for secondary products, leading to reduced beef consumption and a slight increase in mutton and pork. By KMR IIB, mutton consumption and hunting of wild animals, birds, and reptiles increased. In KMR III, the focus on secondary products declined, while the exploitation of smaller wild fauna reached its peak (Goyal et al., 2013; Goyal, 2021).

In Kanmer, KMR IIA and IIB witnessed the most diverse and increased utilization of aquatic animal resources, characterized by a rise in the consumption of fish and mollusks. This trend intensified in KMR III, with a proportionately higher share of fish and mollusks in the diet (Abhayan et al., 2020; Goyal, 2021).

In Shikarpur, throughout its occupation, the inhabitants consistently consumed more cattle and buffalo than sheep and goats, with occasional use of wild mammals. Within the site, the settlers inside the fortifications exhibited a more varied diet, a pattern also observed at Bagasra. Notably, there was a significant decrease in crab consumption: Phase I recorded 229 crab remains, while Phase II showed only 13, alongside considerable fish consumption. By Phase III, there was no evidence of crab consumption, and reliance on fish also decreased (Joglekar and Goyal, 2011; Abhayan et al., 2016).

Although the data from Navinal shows that mollusks were the most abundant fauna group, followed by fish, mammals, and crabs, this data may not be directly comparable to other datasets since it was derived largely from surface surveys (Abhayan et al., 2024b).

The mammalian remains of Kotada Bhadli are dominated by domestic species, particularly cattle, alongside buffalo, sheep, goats, and pigs. There is also significant evidence of the exploitation of wild mammals, including deer, antelopes, hares, and various reptiles. Among the aquatic fauna, mollusks are slightly less represented than fish (Goyal et al., 2018).

The patterns of changes in animal exploitation observed at these sites during the Late Mature Harappan phase and Late Harappan phase are similar to those found at other Harappan sites in Gujarat, such as Rangpur (Nath, 1963), Surkotada (Sharma, 1990), Nageswar (Shah and Bhan, 1990), Kuntasi (Thomas et al., 1996), and Jaidak (Joglekar and Goyal, 2010). An increased rate of freshwater fish (Bagridae) exploitation during the Late Harappan phase at Bagasra (BSR IV) and Late Mature Harappan phase at Kanmer (KMR III) can be analyzed in connection with the significant shift toward the exploitation of wild fauna. During the Late Mature Harappan phase, marine fishery began to decline at Bagasra, as reflected in the fish utilization patterns of residents living outside the fortifications. This decline coincided with a gradual decrease in Harappan settlement at Bagasra, which became more pronounced in the Late Harappan phase (Sonawane et al., 2003). Additionally, a slight decrease in marine fishery during the Late Mature Harappan phase at Shikarpur is also noteworthy in this context.

In comparison to other faunal categories, the presence of fishbones does not constitute a quantitatively significant proportion. However, the fish fauna displays notable diversity. It is important to acknowledge that faunal assemblages recovered from archaeological excavations often carry inherent biases. Many of these biases stem from suboptimal recovery methods employed during excavations. At many sites, the absence of rigorous sieving techniques, both wet and dry, has resulted in a small sample size of fish bones recovered, reflecting the lack of systematic collection. For instance, excavations at Khirsara, another Harappan site in Kachchh, yielded a meager collection of fish remains (i.e., 0.21% of total faunal samples) due to this reason (Joglekar et al., 2013). This bias limits our understanding of the broader spectrum of macrofaunal remains, including fish, birds, small reptiles, and small mammals. In many cases, excavators collect large animal bones, leading to the predominance of large and medium-sized mammals in the faunal assemblages.

Despite the relatively smaller quantities of fish remains, the assemblages demonstrate considerable species diversity, with certain species dominating. A wide variety of fish appear to have been consumed, suggesting that a diverse range of fish species provided different flavors and culinary experiences. This evidence points to deliberate selection, where certain fish species were preferred to meet specific dietary choices. At Kotada Bhadli, the presence of marine fish species supports this hypothesis, indicating a consumer preference for specific types of fish. These preferences were likely driven by demand, with fish being specifically harvested rather than simply gathered opportunistically. This suggests that during the Harappan period, fish played a more nuanced role in the diet, tailored to the tastes and preferences of consumers, rather than being a secondary or incidental food source.

In addition to fish remains, a significant number of mollusk remains have been recovered from Harappan sites. While much of the research has focused on the role of shells, particularly *Turbinella pyrum* in craft production, the culinary importance of edible mollusks has been relatively underexplored (Kenoyer, 1984; Deshpande-Mukherjee, 2023; Ilahi et al., 2023). At sites like Navinal, a substantial collection of edible shells, particularly *Babylonia spirata*, has been documented (Abhayan et al., 2024b). Additionally, numerous shell-midden sites, dating to much earlier periods, have been reported in the vicinities of Harappan sites in the Kachchh region (Prabhakar et al., 2023), further highlighting the significance of aquatic animal resources in the region's subsistence strategies.

Archaeobotanical studies indicate an increased dependence on drought-resistant crops, such as millets, during the Late Harappan phase, attributed to the onset of aridity in the region. This is supported by findings from Kanmer (Pokharia et al., 2011; Goyal et al., 2013), Rojdi (Weber, 1999), and Khirsara (Pokharia et al., 2017) in Gujarat. Furthermore, in this context, the transition in fish exploitation patterns from marine to freshwater during the Late Harappan phases at Kanmer and Bagasra was important for understanding the related cultural changes.

Additionally, lipid residue analysis offers valuable insights into the utilization of aquatic animal resources. Of the 59 ceramic samples analyzed from Kotada Bhadli, one red-ware fragment revealed the presence of "isoprenoid acids (phytanic acid, pristanic acid, and 4,8,12 TMTD), a low concentration of ω-(o-alkylphenyl) alkanoic acids, and long chain mono-unsaturated fatty acids particularly - $C_{20:1}$ and - $C_{22:1}$" (Chakraborty et al., 2020). These findings have been tentatively identified as evidence of aquatic fats, potentially derived from aquatic organisms, which may include fish. Notably, a few vessels associated with a burial from Surkotada, dating to the Early Harappan phase, have also shown traces of aquatic fats (Ghosh et al., 2024).

In addition to aquatic fats, lipid residue analysis has also identified mostly the utilization of ceramic vessels for processing a variety of food materials, including dairy products, ruminant adipose, and non-ruminant adipose at Kotada Bhadli (Chakraborty et al., 2020), as well as from Shikarpur, other sites in north Gujarat such as Datrana, and Loteshwar (García-Granero et al., 2022), and Haryana (Suryanarayan et al., 2021). However, these studies, except Kotada Bhadli and Surkotada have not recorded traces of aquatic fats. However, interpreting lipid residue results can be complex, particularly when different types of food products are processed in the same vessel, which may obscure the distinct signatures of specific lipids (Cramp and Evershed, 2014; Hendy et al., 2018). Garcia-Granero and others (García-Granero et al., 2022) suggest that different cooking practices might explain the lower frequency of aquatic fats in the lipid residue analyses. The presence of charred fish bones in the assemblages implies that fish may have been roasted or fried rather than cooked in vessels, which would leave the ceramics devoid of aquatic fat residues.

6 Conclusion

The analysis of faunal remains from Harappan sites in Gujarat, including Bagasra, Kanmer, Shikarpur, Navinal, and Kotada Bhadli, offers new insights into the region's subsistence strategies, particularly concerning fish consumption. This study highlights the previously underexplored role of aquatic resources in the Harappan diet, demonstrating significant marine-estuarine fishing practices alongside the well-documented pastoralist economy. Aquatic resources are particularly significant in Gujarat, characterized by a long and dynamic coastline and an extensive network of estuarine environments, such as the Rann of Kachchh. In this study, a total of 24 fish species were identified, belonging to 14 families, including Ariidae, Bagridae, Carangidae, Latidae, Carcharhinidae, Dasyatidae, Cyprinidae, Haemulidae, Platycephalidae, Polynemidae, Sciaenidae, Serranidae, Siluridae and Sparidae. The identification of species such as *Lates calcarifer* and members of the Ariidae, Bagridae, and Sciaenidae families points to a diverse fishing strategy that utilized both marine and freshwater environments. Changes in species composition over time, such as an increase in freshwater fish toward the Late Harappan and Late Mature Harappan phases, likely reflect broader environmental shifts and human adaptations to fluctuating situations.

Moreover, the spatial distribution of fish remains within settlements suggests social and economic differentiation, where access to high-quality marine fish may have been restricted to more prosperous groups. The presence of marine species at inland sites, such as Kotada Bhadli, underscores the importance of long-distance trade networks that facilitated the transportation of preserved fish, further integrating coastal and inland economies. The evidence of fish processing practices, such as decapitation and fileting, along with the use of fish bones for tools and ornaments, points to a sophisticated approach to resource utilization and a broader cultural significance attached to aquatic resources, extending beyond their role in subsistence. The role of fish in the Harappan diet was more complex, serving not merely as a secondary or incidental food source alongside red meat. The findings of this study should be considered hypothetical subject to clarification through more compelling data from future ichthyofaunal examinations. It also highlights the need for further ichthyoarchaeological research to uncover comprehensive fishing activities and their role in sustaining both coastal and inland communities within the Harappan civilization.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

GSA: Conceptualization, Data curation, Investigation, Methodology, Writing – original draft, Writing – review & editing. PPJ: Methodology, Supervision, Writing – review & editing. PA: Resources, Writing – review & editing. SVR: Resources, Writing – review & editing. PG: Resources, Writing – review & editing. BC: Resources, Writing – review & editing. JK: Resources, Writing – review & editing. PS: Resources, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Gen AI was used in the creation of this manuscript.

Publisher's note

Supplementary material

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