Current Status of Knowledge on Hilsa

ICAR-Central Inland Fisheries Research Institute
Barrackpore, Kolkata- 700 120, West Bengal

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भाकृअनुप
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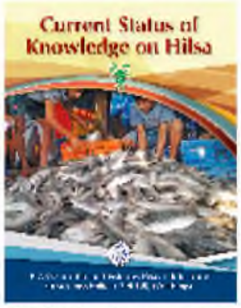

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FOREWORD

Belonging to the family Clupeidae, the group of fish species called hilsa, in eastern region of India and Bangladesh, forms important commercial fisheries in the Indo-Pacific region. By virtue of its nutritional value and taste, the fish is a delicacy and provides livelihood to millions of fishers directly or indirectly along the coastal and riverine stretches in its range of natural distribution. In India, the species is distributed mainly in Ganga, Brahmaputra and Narmada river systems and their estuarine areas. Hilsa has very important cultural and culinary value in West Bengal and other neighboring States in India. However hydrological alterations in the form of barrages and dams built across the major east and west coast rivers, especially along the Ganga and Narmada, have blocked their migratory routes to breeding grounds, resulting in serious decline of its fishery in the rivers. The lucrative commercial fisheries of the fish along the major estuaries in the country, more particularly the Hooghly estuary, have also drastically declined due to recruitment failure and intensified exploitation of adults and juveniles, inviting management interventions for sustaining its natural resources. Conservation and rational exploitation along with reduction of dependence on the natural population, by developing alternate production strategies, have been advocated for management of hilsa resources. To give momentum in this direction, the Indian Council of Agriculture Research, New Delhi has sanctioned a multi disciplinary and multi institutional research project titled 'Stock characterization, captive breeding, seed production and culture of Hilsa (*Tenualosa ilisha*)', through the 'ICAR-National Agricultural Science Fund', New Delhi. The project is operationalized with the ICAR-Central Inland Fisheries Research Institute, Barrackpore as lead centre and the ICAR-Central Institute of Fisheries Education, ICAR-Central Institute of Brackish water Aquaculture, ICAR-Central Institute of Freshwater Aquaculture, ICAR-Central Marine Fisheries Research Institute, ICAR-National Bureau of Fish Genetic Resources and Visva-Bharati University as partners. Although hilsa has been a much studied fish, with works starting from as early as 1907, information on the fish are spread out in various literature, both Indian and overseas. Hence it is appropriate to document the current level of knowledge and identify knowledge gaps for helping research efforts in conservation and management of the fish. I believe that this compilation of information on hilsa will be a ready reference and highly useful for students, researchers and other concerned agencies for enrichment of knowledge on the fish, besides providing support for policy makers. I complement the efforts of the project Scientists and Research Fellows for preparing the document and the Chairman and Members of the Advisory Committee and the Coordination Committee for steering and guiding the research team in bringing out the document.

B K Das
Director
ICAR-CIFRI

PREFACE

Species of the family Clupeidae are highly preferred food fishes in the world. The Indian shad, hilsa, belonging to the family Clupeidae, contribute to commercial catches in a number of countries bordering the Bay of Bengal, Indian Ocean, Persian Gulf and Arabian Sea. The species normally inhabit rivers, estuaries and coastal waters. The highest catch comes from the deltaic region of the Gangetic system in the coastal Bay of Bengal. The fish is anadromous; grows and matures in the sea and migrates to freshwater for spawning. Hilsa fisheries provides direct and indirect livelihood to millions of fishers along the coastal and riverine stretches in its range of distribution. They are highly delicious, priced and has important socio-cultural importance, especially in West Bengal and the north eastern States of India. On account of its commercial importance and migratory habit, hilsa received research attraction since 1907 and there is a wealth of disseminated literature on various aspects of hilsa by researchers of different countries, including India. The ICAR-Central Inland Fisheries Research Institute had carried out pioneering research on its biology, ecology and fisheries since 1950s. Serious progressive decline of its fishery has been recorded, over the years along its range of natural distribution due to hydrological alteration of rivers and estuaries, overexploitation and indiscriminate capture. Conservation of its natural stocks and developing alternate production strategies, have been advocated for management of hilsa. The Indian Council of Agricultural Research, New Delhi has taken a new initiative on management of hilsa fisheries, by sanctioning a multi-institutional research project on 'Stock characterization, captive breeding, seed production and culture of hilsa (*Tenualosa ilisha*)', funded through the ICAR-National Agricultural Science Fund, New Delhi. As part of the project objectives the project team felt the need to compile the national and international knowledge available on hilsa, as available in public domain, in a single document. This document titled 'Current Status of Knowledge on Hilsa' is a result of that effort and presents a topic-wise review on the work done and information available so far on hilsa. We hope that the document would be of immense use to those who wish to work on hilsa and related species of shads all over the world.

We gratefully acknowledge the suggestions and support provided by former Secretary DARE and DG. ICAR, Dr. S. Ayyappan; current Secretary DARE and DG. ICAR, Dr. T. Mohapatra; former DDG (FS), ICAR, Dr. Ms. B. Meenakumari; current DDG (FS), ICAR, Dr. J. K. Jena and Assistant Director General, ICAR-National Agricultural Science Fund, Dr. P. K. Agrawal. Dr. K. K. Vass, Chairman and members of the Advisory Committee Dr. P. K. Agrawal, ADG, NASF; Prof. K. G. Padmakumar, Prof. Bechan Lal and Mr. R. F. Lepcha, have overseen the preparation and finalization of the document. The support received from Prof. A. P. Sharma, former Director, ICAR-CIFRI and Dr. B. K. Das, Director, ICAR-CIFRI, Barrackpore; Dr. W. S. Lakra, former Director, ICAR-CIFE, Mumbai and Dr. Gopal Krishna, Director, ICAR-CIFE, Mumbai, Dr. P. Jayasankar, Director, ICAR-CIFA, Bhubaneswar; Dr. A. G. Ponniah, former Director ICAR-CIBA, Chennai and Dr. K. K. Vijayan, Director, ICAR-CIBA, Chennai; Dr. A. Gopalakrishnan, Director, ICAR-CMFRI, Kochi and Dr. J. K. Jena, former Director ICAR-NBFGR, Lucknow and Dr. K. K. Lal, Director, ICAR-NBFGR, Lucknow and the Vice Chancellor, Viswabharati University, Santinketan are duly acknowledged. We gratefully acknowledge the information and literature shared by Dr. D. K. De, Prof. Amalesh Choudhury and Dr. M. K. Mukhopadhyay for preparing this document.

Authors

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INTRODUCTION

Fishes of the family Clupeidae are among the most preferred food fishes in the world that include herrings, shads, sprats, sardines, pilchards and menhadens (Royce, 1996). Belonging to the family Clupeidae, the hilsa, as commonly called in eastern region of India and Bangladesh, is a group of migratory fish species contributing to commercial catches in a number of countries bordering the Bay of Bengal, Indian Ocean, Persian Gulf and Arabian Sea (Jaffri and Melvin, 1988). The species normally inhabit rivers, estuaries and coastal waters. Among the hilsa fishing countries, Bangladesh and India are the major contributors (Amin et al., 2004), as its highest catch comes from the deltaic region of the Gangetic system in the coastal Bay of Bengal. The fish is anadromous; grows and matures in the sea and migrates to freshwater for spawning (De and Sinha, 1997; Haroon, 1998). Juveniles develop and grow in the freshwater and gradually migrate to the sea, where they spend most of their lives (Hashemi et al., 2010). Hilsa is a group of important and lucrative commercial fish species of the Indo-Pacific region. Due to its nutritional value and taste, the fish is considered a delicacy and provides direct or indirect livelihood to millions of fishers along the coastal and riverine stretches in its range of distribution. It is abundant in the Ganga-Brahmaputra-Meghna river systems of India, Bangladesh and Myanmar, forming one of the most important commercial fisheries in these countries. In India, hilsa is distributed in rivers Narmada, Tapti, Puma, Ulhas, Kali and Vembanad lake on the west coast and Brahmaputra, Ganges, Mahanadi, Godavari, Krishna, Cauvery and Chilika lake in the east coast. In India, the fishery of hilsa is confined to the artisanal fishing sector in the riverine stretches, traditional non-mechanized sector in the coastal areas and small mechanized sector in the near shore waters of the Bay of Bengal and Arabian Sea; with major contribution from the Bay of Bengal along the coastline of West Bengal, particularly the Hooghly estuary and off Gujarat along the Narmada and Tapti estuaries. The marine distribution of hilsa extends from Arabian Sea, with Persian Gulf, Red Sea and Bay of Bengal. Hilsa contributes about 14% to the total fish catch of Ganga-Hooghly river system on the east-coast and 23% along the Narmada estuarine system on the West-coast. Hydrological alterations in the form of barrages and dams built across the major east and west coast rivers, especially along the Ganges and Narmada have blocked its migratory routes to breeding grounds in riverine areas, resulting in the collapse of its fishery in the river stretches above these barrages and as a result, hilsa landing is now concentrated in estuarine part of these rivers (Raja, 1985; De, 1991, 1998). The lucrative commercial fisheries of the fish along the major estuaries, more particularly along the Hooghly estuary, have also drastically declined due to recruitment failure and indiscriminate exploitation of adults and juveniles. There is wealth of disseminated literature on various aspects of hilsa, by researchers of different countries, especially where the fish forms a fishery or have distribution. The fish received attention in India at an early date and investigations began since 1907 (Raja, 1985). First among these was by the Department of Fisheries, Madras, followed the Departments of Fisheries, West Bengal, Bihar and

Orissa. Though there were efforts to consolidate the scattered literature on hilsa, most of them were in the form of bibliographies and were published before 1980's. For the researchers wishing to focus on specific aspects of the species, a compilation of knowledge available on the fish would be of immense help. This document embodies published knowledge on hilsa and related species, covering taxonomy, distribution, ecology, biology, physiology, reproduction, migration, fisheries, nutrient composition, sensory mechanism, artificial propagation and conservation.

DISTRIBUTION

Shads, members of the subfamily Alosinae under family Clupeidae, occur throughout the temperate and tropical regions. The largest concentration of species is of the genus *Alosa*, occur in Europe and eastern North America. Under the genus *Tenualosa*, five species have been recognized from the estuaries and coastal waters of tropical Asia. These are the Hilsa Shad, *Tenualosa ilisha* (Hamilton-Buchannan, 1822); Toli Shad, *T. toli* (Valenciennes, 1847), Longtail Shad, *T. macrura* (Bleekar, 1852), Reeve's Shad, *T. reevesii (Richardson,* 1846) and the Laotian Shad, *T. thibaudeaui (Durand,* 1940). Among these five species, *T. ilisha* and to a certain extent *T. toli* are commonly available in Indian waters. Under the genus *Hilsa*, one species is reported from the Indian region, which is *Hilsa kelee*. Species of the genus *Tenualosa*, other than *T. ilisha* have narrow distribution and most are anadromous, but the extent of anadromy is difficult to assess (Whitehead, 1985) because their life histories are largely unknown. *T. ilisha* inhabits coastal shelf areas, estuaries and freshwater rivers in India, Bangladesh, Indonesia, Sumatra, Myanmar, Pakistan, Kuwait, Iraq and Iran and forms important commercial fisheries in Bangladesh, India, Myanmar, Pakistan and Kuwait (Blaber et al., 2001). But it is most abundant in the Ganga-Brahmaputra-Meghna drainage systems of Bangladesh and India. The distribution of hilsa along the Indo-Pacific region is shown in Fig.1. The marine distribution of the species spreads across the Arabian Sea, with the Gulf and Red Sea, Bay of Bengal, South China Sea with Malay Archipelago. Al-Hassan (1993) described its

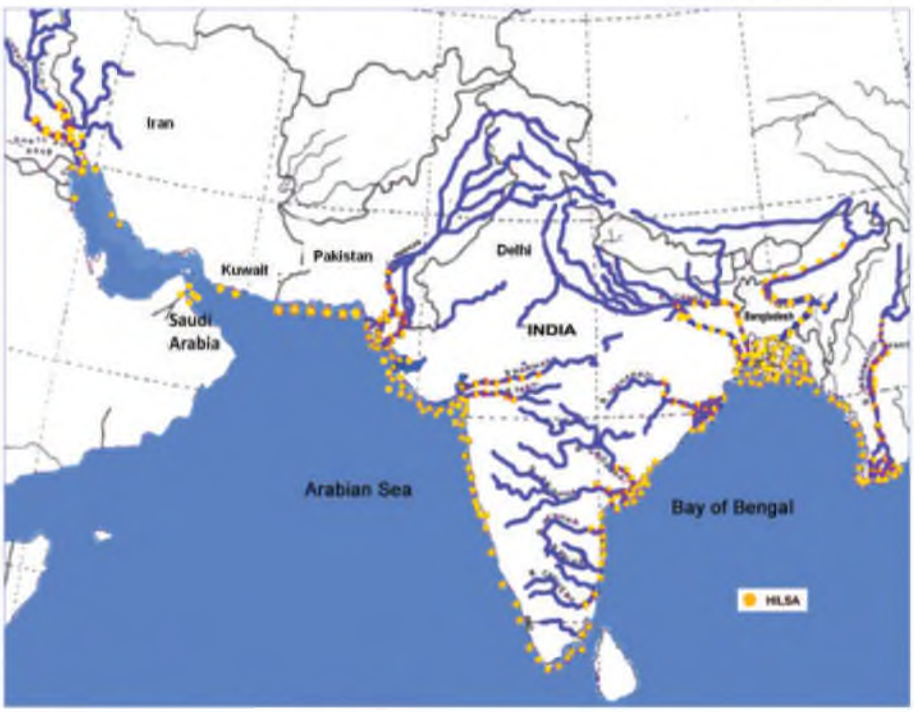


Fig. 1. Distribution of hilsa in Indo-Pacific region

distribution as foreshore areas, estuaries, brackish water lakes and freshwater rivers of the western division of the Indo-Pacific faunistic region. It has also been recorded from the coastal waters of Sri Lanka and Cochinchina (Vietnam) (Pillay and Rosa, 1963). In India, they migrate to the rivers Narmada, Tapti, Puma, Ulhas, Savitri, Kali and the Vambanand backwaters along the west coast and Cauvery, Krishna, Godavari, Mahanadi, Daya, Ganga and its tributaries; Padma, Brahmaputra and Barak and coastal lakes like Chilka along the east coast, although the extend of distribution has reduced due to barrages and hydraulic structures across most of the rivers. Occurrence of hilsa in the seasonal and perennial wetlands of Assam (Kar and Dey, 2002) and lakes of Uttar Pradesh (Banerji, *1955)* has also been recorded. Distribution of the fish in the river systems of different countries is given in Table 1. In general, these distribution range is characterized by relatively large continental shelf, monsoon winds, medium to high precipitation and run-off, surface temperature of 20 to 30 °C, surface currents changing with the change of monsoons, medium to low organic productivity, presence of sub-surface oxygen minimum layer and relatively low salinity of coastal waters (Pillay and Rosa, 1963). The fish is known by different names in different countries as shown in Table 2.

Table 1. Geographical distribution of hilsa

Country	Name of the river systems
Bangladesh	Padma, Meghna, Brahmaputra
India	Ganga, Hooghly, Godavari, Krishna, Cauveri, Padma, Brahmaputra, Narmada, Tapti, Ukai reservoir, Chilika lake
Pakistan	Indus, Jhelum
Iraq	Shatt-al-Arab, Tigris, Euphratis
Iran	Shatt-al-Arab
Myanmar	Irrawady

Table 2. Name of hilsa in different countries

Name	Country	Language
Alose hilsa	France	French
Hilsa	India	English
Hilsa	USA	English
Hilsa herring	United Kingdom	English
Hilsa shad	United Kingdom	English
Hilza indyjska	Poland	Polish
Ilish	Pakistan	Punjabi
Ilish	Bangladesh	Bengali
Ilishmach	India	Bengali
Jatka	Bangladesh	Bengali
Jatka	Pakistan	Punjabi
Nga-thalank	Myanmar	Burmese
Nga-tha-lauk	Myanmar	Burmese
Oolum	India	Tamil
Pala	Portugal	Portuguese
Palasah	India	Telugu
Paliya	India	Kannada
Palla	India	Marathi
Palla	Pakistan	Punjabi
Paluva	India	Other
Pulla	India	Sindhi
River shad	Myanmar	English
Sábalo hilsa	Spain	Spanish
Sevva	Sri Lanka	Tamil
Sevva	India	Tamil
Shour	Iraq	Arabic
Soboor	Iran	Farsi
Ullam	India	Tamil
Ullam	Sri Lanka	Tamil
Valava	India	Malayalam

Source: www.fishwise.co.za

T. toli is found in the Indo-West Pacific, from eastern and western coasts (also rivers) of India, Andaman Sea, Indonesia to Java Sea, Gulf of Thailand and South China Sea. *T. toli* is now mostly found in the estuaries and adjacent coastal areas of Sarawak (north coast of Borneo), Malaysia (Blaber et al., 1996). Presently the species is rarely found in Indian waters, except along the coastline of Gujarat. *T. macrura* is found in Western Pacific, from Malaysia and Indonesia (Java Sea and Sarawak). It is mostly a marine species and has not been recorded in freshwaters. *T. reevesii* is found in the Indo-Pacific region from Phuket Island, Andaman Sea to China and possibly southward into South China Sea ranging from the South East coast of China from 20° to 36° N and Yangtze, Pearl and Qiantang rivers. The species is found in both freshwater and seawater. *T. thibaudeaui* is endemic to Southeast Asia (Mekong river system); also Cambodia and Lower Xe Bangfai in Laos. The species undertakes large-scale upstream migration into Laos. Presently the species occur only in Mekong Delta in Southern Vietnum, including the Tonle Sap lake in Cambodia and lower Xe Bangfai in Laos (Poulsen et al., 2004).

TAXONOMY

The clupeids are characteristically small (<50 cm) in size. However most of them are less than *25* cm, except the shads, whose maximum lengths reach 65 cm *(FAO, 1974)* and are characterized by laterally compressed body, with a keel of scutes along the belly. They possess ray fins one dorsal fin, deeply forked tail and the ventral fins are set far behind the pectoral fins.

Tenualosa ilisha: The species was first described by Russel (1803) with specimens collected from foreshore waters of Visakhapatanam under the name *Palash*. Hamilton (1822) named the fish as *Clupanodon ilisha* and described the species, providing taxonomic status to the species. Since then, the nomenclature of the species has undergone a number of changes when differnent researchers redescribed the species. Jafri and Melvin (1988) briefly listed the different names and researchers who coined these names and re-used the nomenclature in their bibliography on hilsa. The species was described as *Clupea palasah* (Cuvier 1829; Gunther 1868), *Alausa palasah* (Valenciennes, 1847; Jerdon, 1849; Day, 1865), *Alausa ilisha* (Cantor, 1849; Bleeker, 1852; Kner, 1865), *Clupea ilisha* (Gunther, 1868; Day, 1878; Day, 1889; Lloyd, 1907; Tirant, 1929), *Clupea* (*Alosa*) *ilisha* (Steindachner, 1896), *Hilsa ilisha* (Regan, 1917; Fowler, 1934; Shaw and Shebbere, 1937; Misra, 1953), *Macrura i1isha* (Fowler, 1941) and *Tenualosa ilisha* (Munro, 1955; Fisher and Bianchi, 1984). Among the listed names, it was Regan's nomenclature (*Hilsa ilisha*) remained valid until the current redesignation of the species as *Tenualosa ilisha*.

The current classification and major taxonomic features of the species (FAO, 1974) are as following.

Kingdom: Animalia
- Phylum: Chordata
  - Class: Actinopterygii
    - Order: Clupeiformes
      - Family: Clupeidae
        - Subfamily: Alosinae
          - Genus: *Tenualosa*
            - Species: *ilisha*

Binomial name: *Tenualosa ilisha* (Hamilton, 1822)

Identification characters of the species include fusiform body with depth varying from 2.5 to 3.2 times in standard length. Prominent, fairly sharp, keeled scutes on lower belly. Dorsal fin

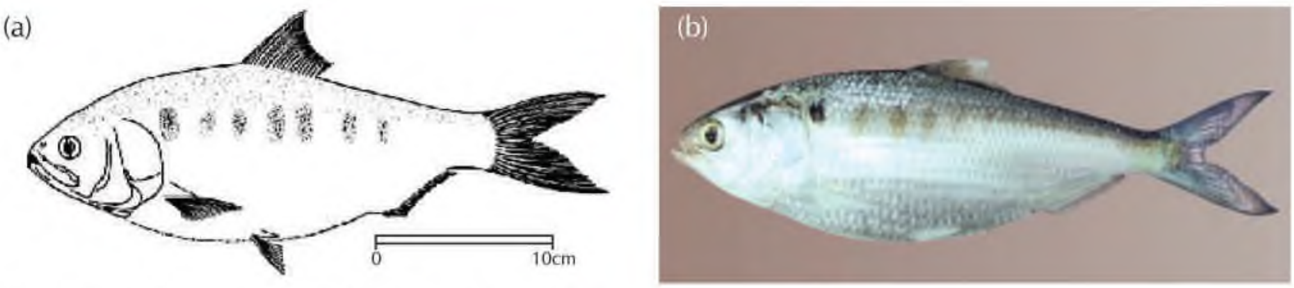


Fig. 2. (a) Sketch of *Tenualosa ilisha (*Source: FAO, 1974) and (b) photograph of the species.

originates at midpoint of the body and the anal fin fairly short with 20-23 rays and it is set well behind the dorsal fin base. The pelvic fins are below the anterior part of the dorsal fin base. The upper jaw has a distinct median notch when seen from the front. Very fine gill rakers (120 to 200 in number) on lower arm of the gill arch. No striated frontoparietal areas on top of the head, unlike other related species. Caudal fin is as long as the head. The body coloration is bluish green on the back and silvery on the flanks. A series of black blotches present along the flanks, which may disappear in larger adults (FAO, 1974). The maximum recorded size is 60 cm (*FAO, 1974)*. A schematic sketch of the fish is shown in Fig. 2.

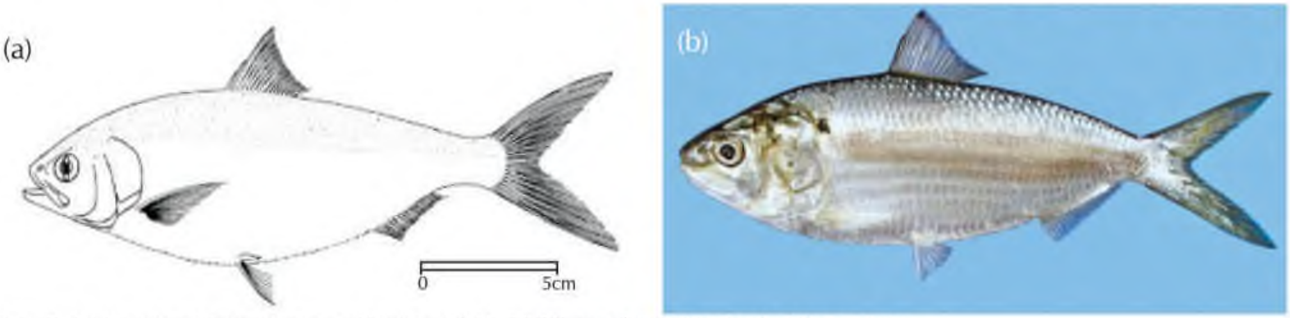


Fig. 3. (a) Sketch of *Tenualosa toli* (Source: FAO, 1974) and (b) photograph of the species.

Tenualosa toli: Similar to *T. ilisha*, the *T. toli* also has a fusiform body, its depth 2.5 to 3.1 times in standard length and the belly has 28 to 30 fairly sharp keeled scutes. The dorsal fin originates a little before midpoint of the body; anal fin is fairly short with 18 to 20 rays and lying well behind the dorsal fin base; pelvic fins are situated below the anterior part of dorsal fin base. The upper jaw is with a distinct notch when seen from the front. The maxilla reaches vertically from the centre of eye or beyond. Gill rakers are fine and numerous

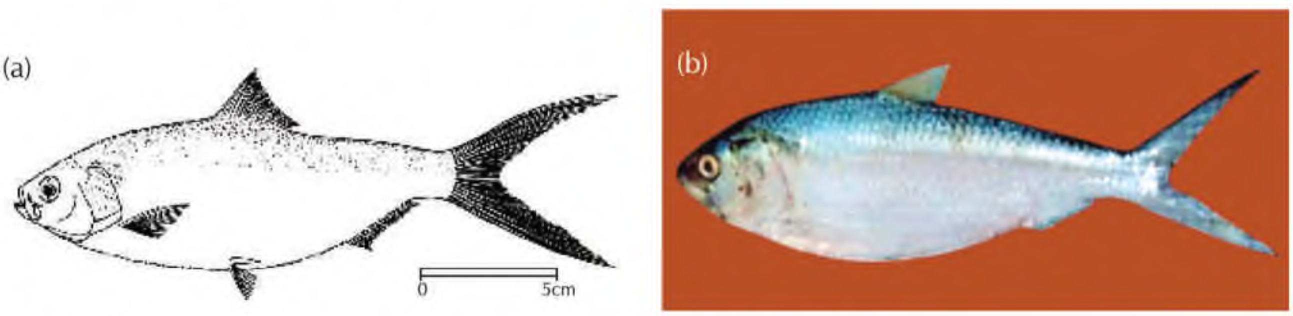


Fig. 4. (a) Sketch of *Tenualosa macrura (*Source: FAO, 1974) and (b) photograph of the species.

(70 to 95 on lower arm of gill arch). Top of head is without striated frontoparietal areas. Caudal fin slightly longer than head. The body coloration is blue green on the back and silvery on the flanks (FAO, 1974). The maximum recorded length is 50 cm; commonly available between 30 and 40 cm (FAO, 1974). A schematic sketch of the fish is given in Fig. 3.

Tenualosa macrura: The species has a fusiform body, with body depth 2.6 to 3.0 times in standard length and belly with fairly sharp keeled scutes. Dorsal fin originate from little behind the midpoint of body and has fairly short anal fin (20 rays) lying well behind the dorsal fin base. The pelvic fins are below the anterior part of the dorsal fin base. The upper jaw is with distinct median notch when seen from the front and maxilla does not reach vertically from the centre of the eye. Gill rakers are fine and numerous (60 to 80 on lower arm of gill arch). The caudal fin is almost twice the length of head, hence giving the name long tail shad. The coloration is blue green on the back and silvery below, but with no spots on the flanks (FAO, 1974). The maximum size reported is 52 cm (FAO, 1974). A schematic sketch of the fish is given in Fig. 4.

Tenualosa reevesii: The species has moderately compressed body; belly with 29 to 34 scutes. Head is large with distinct median notch in the upper jaw. The species has well developed sebaceous eyelids and has fine gill rakers, each raker with scattered asperities. Caudal fin is deeply forked with minute scales. A dark blotch is present behind the gill opening and has a series of spots along the flank. Metallic blue green back, that lightens to silver along the sides (FAO, 1974). The maximum size reported is 61.6 cm (Wang et al., 1998). A schematic sketch of the fish is given in Fig. 5.

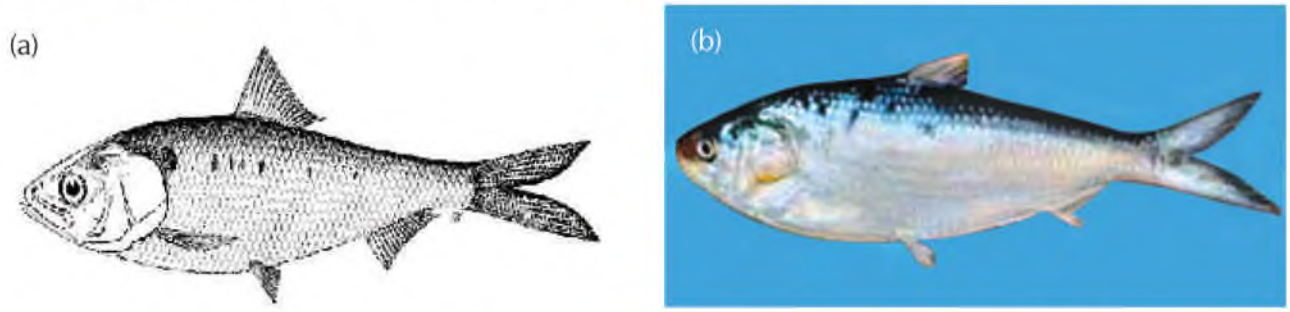


Fig. 5. (a) Sketch of *Tenualosa reevesii* (Source: Froese and Pauly, 1974) and (b) photograph of the species.

Tenualosa thibaudeaui: The species is deep bodied, belly with 28 to 30 scutes. The head is large with a median notch in the upper jaw. Gill rakers are fine and numerous, 204 to 316 on lower arm of the first gill arch (increasing with size of fish); with mucosal buds; no asperities on

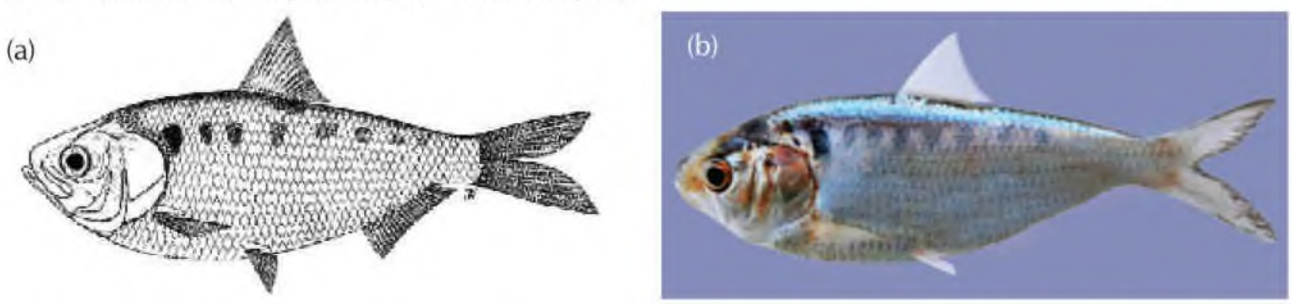


Fig. 6. (a) Sketch of *Tenualosa thibaudeaui* (Source: Froese and Pauly, 1974) and (b) photograph of the species.

upper edges of rakers. Caudal fin is moderate sized. A dark spot is present behind the gill opening and has a series of spots along the flank (*FAO, 1974*). The maximum size reported is 30 cm (SL) (Baird et al., 1999). The schematic sketch of the fish is given in Fig. 6.

Other clupeid species resembling hilsa

Many clupeid species in the distribution range of hilsa in India, show resemblance to hilsa and often misidentified as hilsa, especially in the juvenile stages. Of these clupeids, the three important species in the Indian region are *Gudusia chapra, Gonialosa manmina* and *Anodontostoma chacunda*. Knowledge on the taxonomic features of these species would help avoid misidentification.

***Gudusia chapra*:** The species is available in Asia in rivers of India and Bangladesh, mainly along the Ganges and Brahmaputra systems and the Mahanadi River. In India, it is available Assam, Bihar, Manipur, Orissa, Tripura, Uttaranchal, Uttar Pradesh and West Bengal. The species is also available in Nepal (Shresta, 1994) and Pakistan (Menon, 1999). The species also dwells the floodplain wetlands, especially in West Bengal (Vincy et al., 2005). *G. chapra* is relatively deep bodied and has 26 to 29 scutes along the lower belly. Scales are very small, with 77 to 120 of them along the lateral series, whereas in *T. ilisha*, it counts only 37 to 50. A single triangular pectoral axillary scale is visible in the species. Hind margin of scales are smooth. The flank has series of dark blotches behind the gill opening (Whitehead, 1985). The natural colour of the species is silvery or golden along the flank (Talwar and Jhingran, 1991). Maximum length reported is 20 cm (Whitehead, 1985). A schematic sketch of the species is given in Fig. 7.

(a)

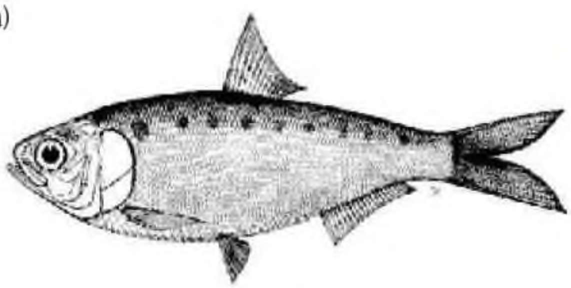
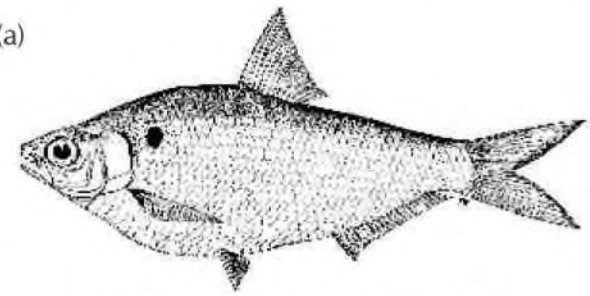


Fig. 7. (a) Sketch of *Gudusia chapra (*Source: FAO, 1974) and (b) photograph of the species.

Gonialosa manmina: Commonly called Ganges Gizzard shad, the species is available in Asia, in the rivers and associated water bodies of Sri Lanka, India (Uttar Pradesh, West Bengal, Assam) and Bangladesh (Whitehead, 1985). *G. manmina* has relatively deep, compressed body. The belly has 27 to 33 (usually 29 to 31) scutes, with 16 to

(a)



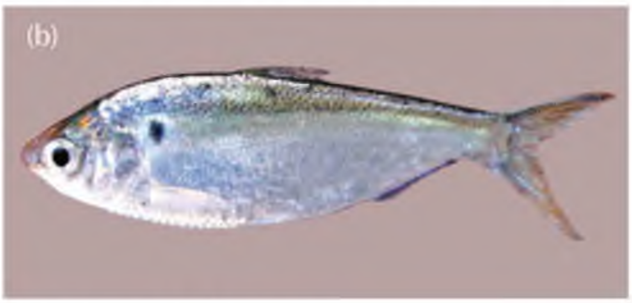


Fig. 8. (a) Sketch of *Gonialosa manmina* (Source: FAO, 1974) and (b) photograph of the species.

20 (usually 17 or 18) prepelvic and 11 to 14 (usually 11 to 13) post-pelvic ones. Upper jaw is slender at the tip and distinctly turned down, with very small second supra-maxilla. Fine gill rakers numbering 90 to 180 on the lower arm of arch. Pre-dorsal scales are paired and overlap in the midline with moderate or small scales (Whitehead, 1985). The coloration is brownish on the back with silvery or golden flanks (Talwar and Jhingran, 1991). The maximum length attained is 14.1 cm (Whitehead, 1985). A schematic sketch of the species is given in Fig. 8.

Anodontostoma chacunda: The Chacunda Gizzard shad has a wider geographical distribution; reported from Andaman Islands (Rajan et al., 2011), Bangladesh (Rahman, 1989), Pakistan, Bahrain, Indonesia, Cambodia, Iran, Iraq, Malaysia (Whitehead, 1985), India (Kapoor et al., 2002), Myanmar (Hla Win, 1987) and Philippines (Herre, 1953). They have oblong, compressed body, with depth increasing with size of fish, which is 40 to 70% of standard length in fishes over 10 cm. The abdomen is serrated with 17 pre-pelvic and 10-11 post-pelvic scutes. The snout is rounded, mouth is small, transverse and sub inferior. Hind edges of scales are toothed, the teeth thinner than the gaps between them; a median series of pre-dorsal scales present. A large black spot is present behind the gill opening (Whitehead, 1985). The body is silvery in colour (Talwar and Jhingran, 1991). The maximum length attained is 22 cm (SL) and commonly available at 14 cm (Whitehead, 1985). A schematic sketch of the species is shown in Fig. 9.

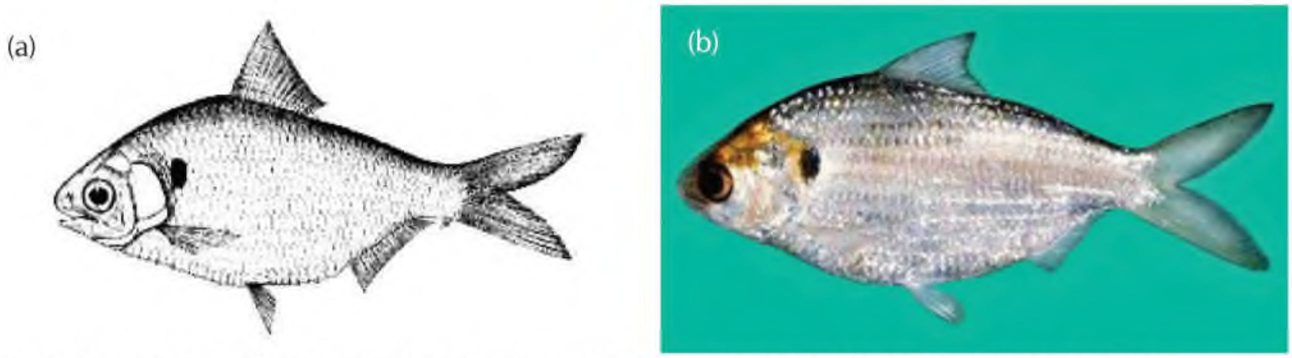


Fig. 9. (a) Sketch of *Anodontostoma chacunda* (Source: www.fishwisepro.com) and (b) photograph of the species.

SOCIO-CULTURAL IMPORTANCE

Hilsa is socially, culturally and religiously important to people living in West Bengal in India as well as in Bangladesh; also to a great extent for many people in other Indian States like Odisha, Bihar and Assam. It is the most popular fish among the Bengali population. The vernacular name of the species in Bengali language is '*Ilish*'. Many say that the name originated from two words; '*Il*', which means 'getting into water' or 'inside the water' and '*ish*' means ruler or master or king. Thus, the meaning of *ilish* stands for the king of water; hence called '*Machher Raja*' in Bengali. The oil in the fish *vis-à-vis* the taste is preferred by Bengali people and the oil is highly palatable while consumed with cooked rice. There are different varieties of preparations and recipes with hilsa, according to various occasions related to ceremonial festivals such as pre-marriage events, wedding ceremony, during the celebration of Bengali New year '*Poila*

Boishak', and celebration of other religious festivals. *Lona ilish* is a traditional, salt fermented product, widely consumed in Bangladesh and Northeast region of India (Majumdar and Basu, 2010). In many Bengali families, buying two hilsa together (*Joda Ilish*) is considered auspicious during Saraswati Puja (worship of the goddess of learning), which takes place in the Spring and on the day of Laksmi Puja (worship the goddess of wealth) in autumn and also during Dussera. '*Jamai Sasthi*', another festival, when the son-in-law is feasted and fed with *ilish*; a *Jamai Sashti* is never complete without at least one dish of *ilish*. There is a custom among Bengali population that they purchase a pair of hilsa on the day of *Vijay Dashami* (in October) and after that they stop eating hilsa till *Basant Panchami* (in February), which is considered as the major breeding season for the species. This practice provided a period of less hilsa consumption and facilitated the fish to breed in its natural waters for replenishment. Such has been the importance of the fish in the Bengali society. The hilsa fishery is by far the largest single species fishery in the Hooghly estuary and has long been important to the economic and cultural heritage of the people of the entire Gangetic plains. Nath et al. (2016) conducted a study on socio economic aspects of the fishers engaged in hilsa fisheries in Hooghly Estuary, which concluded that the dwindling and declining hilsa catch affected livelihoods of fishers and called for policy initiatives for proper management of the resource and welfare of the fishers. Roy et al. (2016) also studied the socio-economic and livelihood features of the hilsa fishers in Hooghly-Bhagirathi river system and reported that poor implementation of mesh size regulation, poor enforcement of closed season in river stretches, ineffective extension services, and recurring climatic hazards mde hilsa fishery more vulnerable and suggested that the government, fishery cooperatives, NGOs and other related organizations need to join hands to support the hilsa fishers for sustainable hilsa fishery management.

HABITAT

A fish's habitat must contain all the physical, chemical and biological requirements needed for that organism to live a healthy life and complete the life cycle, which may include a variety of parameters such as water temperatures, pH, substrate type, turbidity, depth, water velocity, nutrient levels, availability of food, etc. and accessibility to migration routes in specific for migratory fishes. Being an anadromous species, hilsa has efficient osmoregulatory mechanism and is able to tolerate a wide range of salinities during its different stages of life cycle. Temperature, rain-fall, water current, water flow, turbidity, etc. might influence the breeding, migration, growth and other physiological characters of hilsa. Though there are several studies on the environmental requirements of hilsa, very little is known about the factors that induce spawning and migration. Southwell (1914) suggested that the changes involve transition from the sea to freshwater to induce spawning. Nair (1958) suggested that high temperatures have perhaps an inhibitory effect on maturation of the ovaries. Several attempts have been made to correlate physico-chemical parameters of Hooghly-Bhagirathi river system and abundance of hilsa as well as their upstream and downstream migration. Studies in Hooghly estuary revealed bimodal variation of water temperature with major peak during March-June and minor peak during September-October (Lal, 1990). This peak however varies from year to year and sometimes extends up to August-

September and January-March. Temperature of river-estuarine water has been observed to drop by 1.5 °C from an average of 31.3 °C (29.5-32.6 °C) to 29.8 °C (29.3-30.2 °C) during monsoon when the fish migrates for breeding. On the other hand, in late winter (February) the ambient temperature rises by 1.8 °C from average of 27.6 °C (26.8-28.4 °C) to 28.6 °C (27-31.8 °C), which might influence upstream migration and breeding of hilsa (Bhaumik et al., 2011a). Bhaumik et al. (2011a) opined that the monsoon runoff of turbid water, above 100 NTU, preferably 100-140 NTU is a requisite for attracting shoals of brood hilsa to the Hooghly-Bhagirathi system. Higher transparency during winter months was recorded by earlier workers (Gopalkrishnan, 1971; Nath, 1998). Depth plays a limiting role in movement of the migrating hilsa. Although, the fish passes through comparatively lower depth (on an average of 10 m) in winter months (Bhaumik et al., 2011b), water column of 18-20 m has been suggested to be ideal for stress free movement of the brood stocks. Hora (1943) reported severe scarcity of freshwater discharge through the river Hooghly, with as low as one foot, during low tide. Higher freshwater discharge through feeder canal in post-Farakka period significantly increased the water depth of Hooghly estuary. The same locations, as indicated by Hora (1943), are now retaining about 6-8 m water depth throughout the year. Among the chemical factors, salinity might be playing a determining role in breeding migration of hilsa into the rivers. A salinity range of 0.004-0.2 ppt (sometimes even up to 1.16 ppt) was recorded from Barrackpore stretch of the river by David (1954) during pre-Farakka barrage period. However, increased freshwater inflow by water diversion through Farakka barrage changed the entire salinity scenario of the Hooghly estuary. Similar range of salinity that was observed by David (1954) at Barrackpore-Nawabganj region are now be found beyond Godakhali-Uluberia region, about 60 km downstream. Nandy et al. (1983) suggested the need for redefining of zones in Hooghly estuary considering the effect of discharge from Farakka barrage. Dissolved oxygen content of the system fluctuates in the range of 5-7 ppm. However, during monsoon, the average dissolved oxygen values increase by 1.22 ppm from 4.63-5.85 ppm (Bhaumik et al. 2011a). Significant improvement of dissolved oxygen (4.7-10.6 ppm) in Hooghly estuary during post-Farakka barrage period was described by Nandy et al. (1983) as compared to that in pre-Farakka barrage period (3.4-5.1ppm) as reported by Bose (1956). Higher dissolved oxygen (8.5-11.5 ppm) in post-Farakka barrage was also reported by Lal (1990). Specific conductivity, an indicator of dissolved ions in water, signifies the mixing process influenced by tides and the magnitude of intrusion of saline water *vis-a-vis* freshwater influx into the estuary. Reduction of specific conductivity of water with monsoon rain was reported in large Indian rivers like Brahmaputra (Manna and Sarkar, 2008). Nandy et al. (1983) reported a specific conductivity range of 143-43538 mhos/cm in Hooghly estuary. Similar specific conductivity value of 40400 μS/cm was reported by Nath (1998) from Fraserganj. The researchers opined that Hooghly system provides constant alkaline environment (pH 7.7-8.3) for the fishes (Bose, 1956; Ray, 1981; Lal, 1990; Nath, 1998) and also a good buffering environment (Nandy et al., 1983). Higher pH was reported in freshwater zone of the Hooghly estuary by Nath (1998). Nath (1998) noted higher total alkalinity in freshwater and gradient zone, recording a range of 103-139 ppm of total alkalinity. As salinity increased, total alkalinity decreased (Ray, 1981). Before construction of Farakka barrage, Basu (1965) reported a total alkalinity range of 176-232 ppm in Hooghly estuary. Significant lowering of total alkalinity in post-Farakka barrage period (40-195 ppm) was reported by Nandy et al. (1983) as compared to that in pre-Farakka barrage period (102-357 ppm) as reported by Bose (1956). Lal (1990) also noted similar lowering of total alkalinity during post-Farakka barrage period (75-147 ppm). Post-Farakka scenario of total hardness along with calcium and magnesium was reported by Nath (1998) and Nath et al. (2004). However the habitat requirement of the fish for growth, maturation and breeding are still not clearly known and mechanism that triggers their migration is also not well known.

LIFE CYCLE

The life cycle of hilsa resembles American shad, *Alosa sapidissima* (Bhuiyan and Talbot, 1968). It has also some similarity with European shads, *Alosa alosa* (Allis shad) and *Alosa fallax* (Twaite shad) (Aprahamian, 1982; Bristow, 1992). Hilsa, after spawning in fresh water, return to the sea where they remain until the next breeding season. However, this life cycle is not followed by all stocks/races of the species; some do not migrate from the sea to the river or vice versa (Blaber *et al.*, 2003; Rahman, 2006). Hilsa spawns in fresh water and the eggs hatch after 19-25 hours at an average temperature of 23 °C (Jones and Menon, 1951). The size of the hatchlings varies between 2.3 and 3.1 mm (Kulkarni, 1950; Motwani et al., 1957; Karamchandani, 1961). When the larvae can swim, they try to find suitable nursery grounds, normally in the lower region of the rivers or in coastal waters. In Bangladesh, the juvenile hilsa are called *Jatka* that resembles adult *Gudusia chapra* (Rahman and Haldar, 1998). The *Jatka* remains in the nursery grounds for about 5-6 months and attain a maximum size of 15-16 cm (Raja, 1985; Mazid and Islam, 1991). At 10-12 cm length they migrate to the deeper parts of the river and at about 12 cm, acquire the ability to tolerate saline water and move down to the estuary, where they spend young life stages (Rahman and Haldar, 1998). Later, the young ones move offshore for feeding and grow to adult size. After maturation, the adults again migrate back in to rivers for spawning to compete the life cycle. A schematic sketch of the life cycle of the fish is depicted in Fig. 10. To confirm the status of *Jatka* and rule out the ambuigieties of fishermen and authorities that *Jatka* may be different from adult fish, Rahman and Naevdal (1998) compared the genotypes and and concluded that *Jatka* from inland nursery grounds along Bangladesh are indeed young hilsa. .

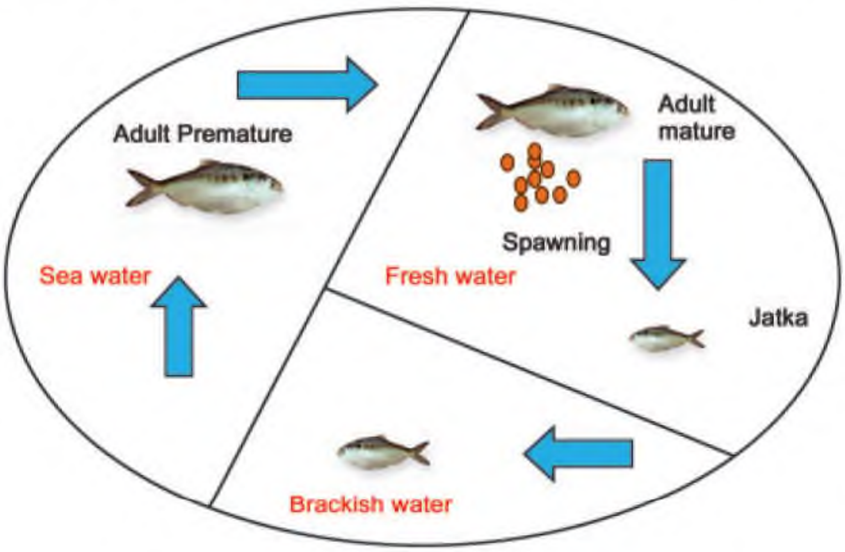


Fig. 10. Life cycle of hilsa (Source: Haldar et al., 2005)

AGE AND GROWTH

Age and growth data are necessary for scientific management of fisheries as it is an important input in population studies and stock assessment. The early works on age and growth of hilsa are that of Hora (1938), Hora and Nair (1940 a and b), Job (1942), Chacko et al. (1948), Chacko and Krishnamurthy (1950), Jones and Menon (1951), Sujansingani (1957), Pillay (1958 a and b), Pillay and Rao (1963), Jhingran and Natarajan (1969), Ramakrishnaiah (1972), Rajyalakshmi (1973), Quddus (1982), De (l986) and De and Datta (1990a). Hora (1938) gave a preliminary description of early growth of hilsa, stating that hilsa of July-August brood might attain a length of 140-150 mm by November, in about four months. Hora and Nair (1940a) estimated an average monthly growth increment of 30 mm for the first five months and 20 mm for the next seven months. They also stated that the monthly growth increment was low in November (35 mm) and higher in summer (50 mm). The observation of Sujansingani (1957) differed from Hora and Nair (1940a); in that the monthly growth increment was 28 mm in the first month, 15-20 mm in the second to third months and 10 mm afterwards for hilsa from river Hooghly. Hora and Nair (1940b) reported slower growth in April-May. According to Job (1942), hilsa has a growth rate of 2.54 cm/month and attains a size of 26.48 cm in a year. Jones and Menon (1951) observed that the hilsa of July-August brood in Chilika Lake grew to 110-133 mm by first week of December, indicating a slower growth rate than that recorded by Hora (1938) in Ganges, however was similar to that reported by Sujansingani (1957) from river Hooghly. Pillay (1958b) stated that the male hilsa in Hooghly attained modal lengths of 247, 343 and 393 mm and females 265, 391, and 436 mm in 1.5, 2.5 and 3.5 years, respectively, indicating differential growth of males and females. With regard to the age and growth of hilsa, a number of well documented literature are available from different ecosystems as shown in Table 3. The age and growth of juvenile hilsa from the freshwater stretch of Hooghly river was studied by De (1986) using length-frequency method. The largest size description of hilsa from India so far is 614mm and 4250g, collected from Tapti estuary Gujarat (Bhaumik et al., 2012). Sandhya et al. (2016) reported hilsa of 573 mm from Hooghly estuary, which is considered to be largest hilsa specimen recorded so far from the West Bengal waters.

The maximum size recorded so far is 60 cm and females are larger than males (Whitehead, 1985), while the estimated age of hilsa from various water bodies were dissimilar. However the reported lengths and age at maturity obtained by Pillay (1958b), De (l986) and De and Datta (1990a) were comparable. Jhingran and Natarajan (1969) reported that the fish grows to 217 mm in one year and 357 mm in 2 years in Chilika Lake. The observations of Ramakrishnaiah (1972) for Chilika Lake shows a growth of 237 mm in 1 year and

Largest hilsa recorded (573mm TL) from Hooghly estuary
Source : Sandhya et al. (2016)

Table 3. Age (year) and length (mm) of hilsa from different ecosystems as reported by various authors

Hooghly estuary (Pillay, 1958b)		Hooghly estuary (De 1986; De and Datta1990a)		Off Hooghly estuary (Reuben et al., 1992)		Brahmaputra (Choudhury, 1990)	
Age group	Length (cm)	Age group	Length (cm)	Age group	Length (cm)	Age group	Length (cm)
1.5	24.7-26.5	1	18.9	1	23.8	1	23.0
2.5	34.5-39.1	2	27.7	2	37.2	2	33.0
3.5	39.3-43.6	3	35.1	3	45.6	3	41.0
		4	41.3	4	50.8	4	47.0
		5	46.6	5	54. 1		
		6	51.1	6	56. 1		
Godavari estuary (Pillay and Rao, 1963)		**Godavari estuary (Rajyalakshmi, 1973)**		**Chilika lake (Jhingran and Natrajan, 1969)**		**Chilika lake (Ramkrishnaiah, 1972)**	
Age group	Length (cm)	Age group	Length (cm)	Age group	Length (cm)	Age group	Length (cm)
+1	35.5	1	0-21.0	1	21.7	0	16.2
+2	41.5	2	18.5-31.0	2	35.7	1	23.7
+3	45.5	3	29.4-41.2			2	38.7
+ 4	48.5	4	39.5-49.3				
+ 5	50.5	5	48.8-56.0				
+ 6	52.5	6	56.0-6 1.0				

387 mm in 2 years, closely following the estimates by Jhingran and Natarajan (1969).

Pillay and Rao (1963) designated modal lengths for Godavari hilsa at 355, 415, 455, 485, 505 and 525 mm at 1, 2, 3, 4, 5 and 6 year age groups, respectively. Rajyalakshmi (1973) also studied growth of Godavari hilsa and observed that winter recruits gained 100 mm length in four months (February to June) and also traced growth increment of 125 mm (from 88.5 mm to 213. 5 mm) during a period of seven months from November to June.

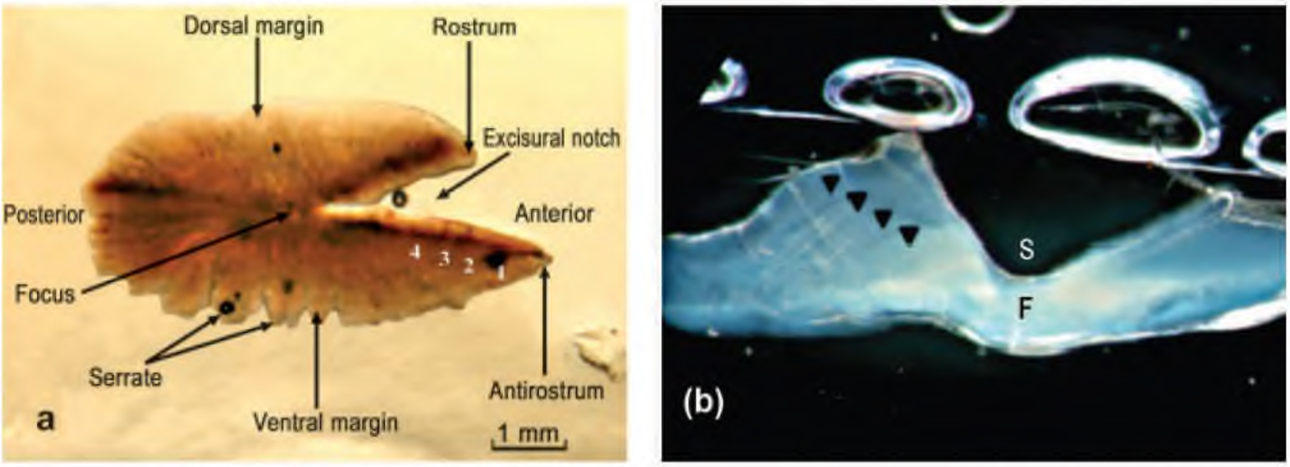


Fig. 11. Right otolith of *T. ilisha* (lateral view of distal side); numbers are indicate year marks (a); sectioned otolith showing four year marks (annuli), S=Sulcus, F=Focus (b). Source: Ahmed et al. (2008)

Lack of suitable method for determining age and growth of the fish has been one of the major constraints. Although length-frequency method has been adopted since beginning, it has its own limitations as hilsa stocks are mostly caught by selective gears. Hard parts like scales and otoliths have been used; the results were not so encouraging in the earlier works. Hora and Nair (1940a), Prasad et al. (1940), Chacko et al. (1948), Chacko and Krishnamurthy (1950), Jones and Menon (1951) and Pillay (1958 a and b), have tried to interpret growth or spawning marks found on the scales, but the results have not been conclusive. A study of 1100 specimens from river Godavari showed that radii of the scales from pectoral region represent growth of the fish (Chacko et al., 1948). Chacko and Zobairi (1949) described the significance of accessory rings on the scale of hilsa. Raj (1951) expressed insufficiencies in scale method for the determination of age of hilsa by stating that annuli are ill defined; instead the radii provide a better evidence of the age. He observed that two year old hilsa from Bengal and Madras bore several radii on the scales, which corresponded to size of fish in inches and was found correct for hilsa from Iraq too. Pillay (1958a) has concluded that the number of radii on the scales is not related to the age of the fish, hence of no use in determining either age or growth rate of the species.

Otolith has been another hard part that was studied for determining age of the fish. Otoliths are paired calcified structures used for balance and/or hearing in all teleost fishes. Otolith, as well as other bony structures form yearly rings called annuli as growth marks. Each annulus is composed of opaque and transparent zones, which correspond to periods of fast and slow growth. The occurrence of opaque and hyaline material at the margin of the otolith through an annual period suggests periodicity in the ring formation, which might be true for hilsa. The otolith of *T. ilisha* is shown in Fig. 11 a, b; the opaque rings are broader, suggesting that they equate with the fast growth or summer rings based on the assumption that the rings were laid down annually (Ahmed et al., 2008).

Analyzing the size, shape and microstructure has been another approach in ageing hilsa (Quddus, 1982; Quddus et al., 1984a; Mazid, 1998; Blaber et al., 2003). Quddus et al. (1984a) compared the age and growth of two types of hilsa (slender and broader) from Bangladesh using otolith and observed that body length otolith size relationship was linear for both types of hilsa. The study by Rahman and Cowx (2006) revealed the influence of lunar cycle on the formation of growth rings (increments) on otolith through examination of otolith microstructure. The daily increments were grouped with the two tidal phases, viz., neap tide and spring tide period of the 14 day lunar cycle. Blaber et al. (2003) also studied daily growth increments on otoliths of *T. ilisha* and reported similar ages of similar sizes of the fish, but did not indicate any lunar periodicity. The age at length of *T. ilisha* estimated by Rahman and Cowx (2006), using otolith reading combined from Meghna and Padma rivers from Bangladesh is shown in Fig. 12.

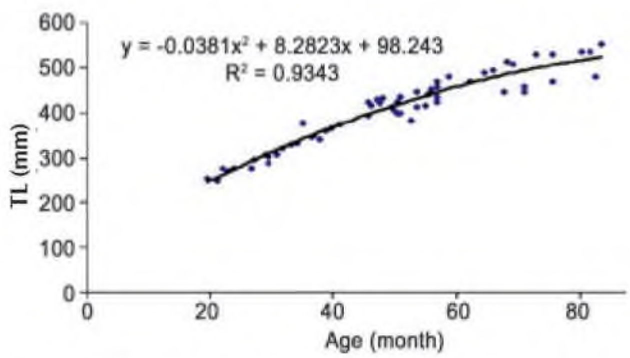


Fig.12. Relationship between total length (mm) and age (month) of *T. ilisha* in Bangladesh. Data based on otolith reading combined from the Meghna and Padma rivers. Source: Rahman and Cowx (2006)

Table 4. Summary of the annual growth rate of *T. ilisha* in Bangladesh based on the backcalculated length using polynomial relationships between total length (mm) and age (month)

Sex	Annual growth of *T. ilisha* (mm)						
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
Male	195	273	339	392	432	460	475
Female	191	275	355	420	474	517	548
Combined	192	275	347	408	458	497	525

Source: Rahman and Cowx (2006)

A summary of annual growth of *T. ilisha* from Bangladesh, as reported by Rahman and Cowx (2006) is given in Table 4. However in spite of all these studies the ageing of hilsa remained difficult and unclear. The age at length calculated for the species from various river systems is shown in Fig. 13.

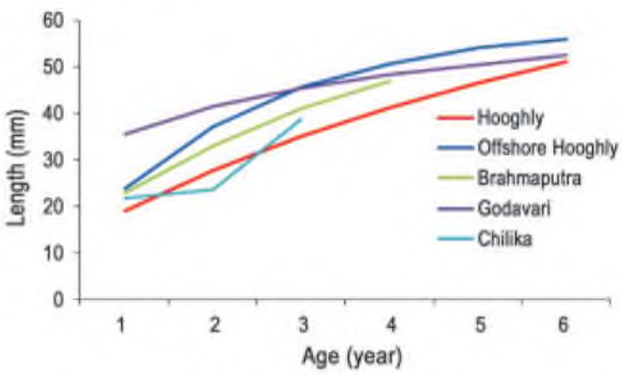


Fig. 13. Age at length calculated for the species from various river systems

LENGTH-WEIGHT AND CONDITION FACTOR

The length-weight relationship is an important parameter to understand the growth dynamics of fish populations. The relationship is used for estimating the weight corresponding to a given length of the fish. The study of the length-weight relationship in fishes is also of primary importance in setting up yield equations (Beverton and Holt, 1957; Ricker, 1958), in estimating the number of fish landed and in comparing populations in space and time. The general expectation is that the weight of fishes would vary as the cube of length, i.e., $W = aL^3$ (Brody, 1945; Lagler, 1952; Rounsefell and Everhart, 1953; Brown, 1957). But the actual relationship may depart significantly from this (Le Cren, 1951), as fishes normally do not retain the same shape or body outline throughout their life span and the specific gravity of the tissues may not remain constant. Values of W usually have been calculated from the logarithmic (base 10) equivalent: $\log W = \log a + b \log L$. A graph of log W against log L forms a straight line with a slope of b and a Y-axis (log W) intercept of log a. The length and weight of *T. ilisha* and the relationship between them were investigated in the rivers of Bangladesh (Ahsanullah, 1967). The maximum weight recorded for *T. ilisha* by Ahsanullah (1967) was 2 kg, while the size range of 250-1375 g constituted the bulk of the population with higher weight during the summer (May-September) the winter months (December-March). The length weight relation of *T.ilisha* has been studied by many workers with the help of various equations expressing different curvilinear regressions (Table 5). For the Hooghly hilsa, Pillay (1958 b) found that the exponential curve as the best fit. Similarly, length-weight relationship of the species was studied by various

Table 5. The length-weight relationship of hilsa estimated by different workers from different countries

Author (s)	Sample size	Length (mm)	Weight (g)	Equations	Country	Location / system
Pillay (1958b)				Adults (male and female): $W = 10.0249\ e^{0.1092L}$ Immature: $W = 0.1402\ e^{0.4085L}$	India	Hooghly
Swarup (1966)	463 (male); 260 (female); 247 (Combined)			$W = 14.76\ e^{0.0907L}$ $W = 24.32\ e^{0.0777L}$ $W = 1.66\ e^{0.2012L}$	India	Ganga (Allahabad)
Ramkrishnaiah (1972)	214	125-509		$\text{Log } W = 5.35 + 3.125 \log L$ $W = 0.000004468\ L^{3.125}$	India	Chilka lake
Islam et al. (1987)				$W = 0.0305\ L^{2.73}$ $W = 0.0177\ L^{2.76}$ (male) $W = 0.0269\ L^{2.89}$ (female) $W = 0\ 028\ L^{2.74}$ and $W = 0.021\ L^{2.87}$	Bangladesh	Chittagong Khepupara Chandpur
De and Datta (1990a)	193 (female)	175-545 (f) 220-452 (m)	150-2,100 (f) 140-1,075 (m)	$\text{Log } W = -4.4080 + 2.8083 \text{ Log } L$ (female) $\text{Log } W = 4.6821 + 2.9066 \text{ Log } L$ (male) $\text{Log } W = 4.8235 + 2.9611 \text{ Log } L$ (general)	India	Hooghly
Reuben et al. (1992)	1300			$W = 0.00003693321\ L^{2.8053}$	India	West Bengal and Orissa
Al-Baz and Grove (1995)		140-570		Male: $W = 0.011\ L^{2.983}$ Female: $W = 0.007\ L^{3.104}$	Kuwait	
Amin et al. (2004)				W=0.01351 TL2.974 W=0.02132 TL2.820 W=0.0087 TL3.077	Bangladesh	
Amin et al. (2005)		29.03-mean (male) 34.23-mean (female)	265.8-mean (m) 520.38 mean(f)	Log weight = -2.516 + 3.381 Log $W = 0.00305\ TL^{3.381}$	Bangladesh	
Narejo et al. (2008)	160 (slender) 120 (Broad	101-500 (m) 101-350 (f)		$\text{Log } W = -2.13 + 3.03 \text{ Log } L$ (males type A) during summer $\text{Log } W = -2.16 + 3.08 \text{ Log } L$ (females type A) during summer $\text{Log } W = -3.08 + 3.81 \text{ Log } L$ (male type B) during winter $\text{Log } W = -3.05 + 3.83 \text{ Log } L$ (female type B) during winter	Pakistan	Indus
Bhaumik et al. (2011b)	1079	2307-425 (m) 206-525 (f)	140-780 (m) 110-1700 (f)	$W = 0.00013\ L^{2.57}$ (male) $W = 0.0000038\ L^{3.20}$ (female) $W = 0.0000064\ L^{3.11}$ (combined)	India	Hooghly
Dutta et al. (2012b)	550	311.9 (mean)	387 (mean)	$W = 0.000006\ L^{3.109}$	India	Bay of Bengal

workers like Swarup (1966) from Ganga near Allahabad, Ramkrishnaiah (1972) from Chilika, Rajyalakshmi (1973) from Godavari, De and Datta (1990a) from Hooghly, Reuben (1992) from the rivers of West Bengal and Orissa, Bhaumik et al. (2011b) from lower stretches of Hooghly, Dutta et al. (2012b) from Bay of Bengal, Shafi and Quddus (1974), Shafi et al. (1978a), Quddus (1982), Amin et al. (2004 and 2005) from Bangladesh waters. Narejo et al. (2008) fitted the linear regression equation for the relation for hilsa from the river Indus, Pakistan. Al-Baz and Grove (1995) also showed the same relation through in the fish from Kuwait.

Condition factor is used for comparing the 'well-being' of a fish (Tesch, 1968), based on the assumption that heavier fish of a given length are in better condition. Both concepts have been used in fisheries research since the beginning of the 20^{th} century. Such indices provide an indirect means of evaluating ecological relations and the effects of various management strategies. The traditional approach to the assessment of condition involves the use of Fulton's condition factor (Anderson and Gultreuter, 1983). Fulton's condition factor is calculated using the equation, $K=W/L^3$; where W is weight and L is length. These condition factors are both length and species-dependent. While the relative condition factor K_n (Le Cren, 1951) is estimated from the calculated weight of the fish from length weight relation in comparison to the observed weight. $K_n=W/W^1$, where W is the observed weight of fish and W^1 is the estimated weight from length weight relation. In *T. ilisha*, Pillay (1958b) showed a steady increase in the relative condition values of immature fish up to a mean length of about 8 cm; after which the values fell gradually. The K_n values of male fish also showed a similar trend of increase till a mean length of 28.5 cm. After which the values fell almost steadily till a minimum K_n value of 0.8970 was reached at a mean length of 43.5 cm. The curve of variation in the K_n values of females also showed the same trend. The highest condition reached at a mean length of 30.5 cm, after which there is a gradual fall till the minimum K_n value of 0.7600 is reached at a mean length of 48.5 cm. Ramakrishnaiah (1972) showed a gradual decline in the condition as the fish grew to a size of 162 mm and thereafter a sudden increase was noted at 187 mm. Subsequently two peaks were observed at 287 and 337 mm in specimens from Chilika Lake. The studies were in conformity with the findings of Rajyalakshmi (1973) and Shafi and Quddus (1974). Shafi and Quddus (1974) observed two peaks; first at 300 mm and the other at 450 mm. Two peaks were also reported by Rajyalakshmi (1973) from the Godavari hilsa; one peak occurred at lengths of 404.5-434.5 mm and 494.5-514.5 mm for the size range 374.5 to 584.5 mm. From Bangladesh, Islam et al. (1987) reported that the range in K_n values for different size groups is 0.75 to 1.15. According to De and Datta (1990a) fluctuations of K_n of female hilsa at different lengths showed that the values were found to be maximum in small size groups (185-245 mm). High K_n values in the small size groups was attributed to high feeding intensity. The first lower value of K_n was observed among the fishes belonging to length around 345 mm. The study by Narejo et al. (2008) also worked out relative condition factor for two populations. The mean values of K_n were 1.01 and 1.0 for male and female respectively during summer, while 1.06 and 1.02 for males and females, respectively during winter.

FOOD AND FEEDING HABITS

Gut morphology: The digestive system of hilsa includes pharyngeal organ, bucco-pharynx and the gut (Fig. 14). Hilsa has terminal and slightly upturned mouth, which is surrounded by thin upper and lower lips. The fish has four pairs of gill arches that support gill filaments and rakers on its outer and inner surface, respectively. The gill rakers are very fine and elongated, with about 120 to 200 in number in the lower arm of the gill arches. In general, fishes with long, fine, closely set gill rakers are mostly filter feeders (Kapoor et al., 1975). The pharynx leads into a short, moderately thick walled esophagus. The stomach is a 'V' shaped muscular tube, which is divisible into two parts, the anterior cardiac stomach and the posterior pyloric stomach. The pyloric stomach and the anterior part of the intestine are covered with thick pyloric caeca (De and Datta, 1990b).

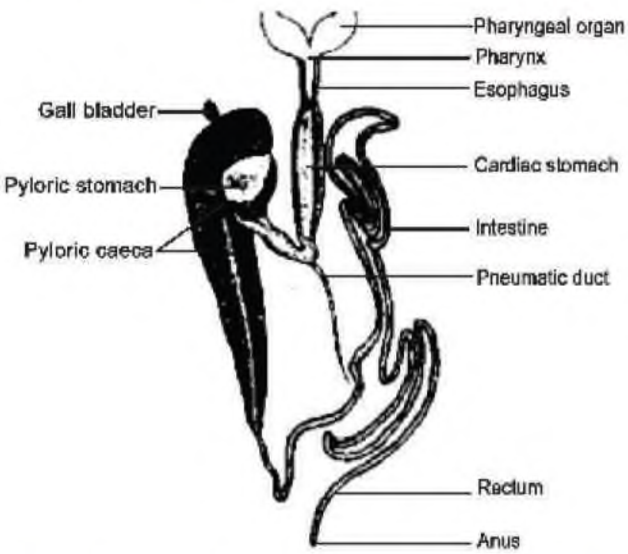


Fig. 14. Gut morphology of hilsa (Source : De and Datta, 1990b)

Histological studies of alimentary canal of the fish (Swarup, *1959;* De, 1986; De and Datta, 1990b) revealed that taste buds are completely absent in buccal cavity, pharynx, pharyngeal pouch and esophagus. Mucous cells are completely absent in cardiac and pyloric stomach but these are well compensated by the presence of gastric glands. In pyloric stomach, muscular layers are well developed and is the thickest layer of the alimentary canal. Morphology of digestive tract of river hilsa indicated presence of feeding adaptations. The absence of teeth in the mouth, presence of an efficient filtering mechanism in the form of fine, long gill rakers, the pharyngeal organ and the modification of stomach into gizzard, indicated filter feeding, in which the food items are consumed by size and not by kind. The upturned mouth, large eyes and the absence of barbels and taste papillae in the lips are characteristic features of its sight feeding habit (Jafri, 1988). In adult hilsa, the fully developed gill rakers with minute papillae form an efficient filtering mechanism for sieving minute food organisms, while less developed gill rakers without papillae in fish below 50 mm may not have such efficient filtering capability (De and Datta, 1990b). Short, narrow and cylindrical esophagus indicates its planktivorous habit. Carnivorous and predatory fish possess longer and dilated esophagus (Mehrotra and Khanna, 1969). In hilsa, absence of teeth and masticatory apparatus in the mouth and pharynx respectively compensate the presence of a highly developed gizzard stomach. Muscular gizzard like pyloric stomach can be used for crushing the food components and organic matter. De and Datta (1990b) found that the RLG (Relative Length of Gut) ranged between 0.86 and 1.14, indicating that after attaining the size of 51 mm there is a gradual shifting from zooplankton feeding habit to a mixed diet. However, adult hilsa subsisted mainly on copepods, organic matter, green algae, diatom and rotifer in order of preference. RLG value varied from 0.86 to 1.87 among the fish of different length groups from 59 to 525 mm. It has been documented that development of a gizzard may be considered as one of the series of gut specializations such as, loss of teeth, development of pharyngeal organ, well-developed gill rakers and moderately long intestine, indicating micro-phagous habit (Nelson, 1967). Increase in relative length of gut (RLG) value from fry to large adult hilsa (Table 6) indicated the changes in food and feeding habits in the same environment (De and Datta, 1990b).

Table 6. Relative length of gut (RLG) of fry and adult hilsa

Length (mm)	Sample size	RLG (mm)	Average
59-99	9	0.86-1.14	1.05
115-161	2	1.08-1.17	1.13
230-285	10	1.26-1.55	1.37
309-392	21	1.35-1.70	1.47
401-475	12	1.43-1.77	1.5
510-525	4	1.80-1.87	1.82

Source: De and Datta (1990b)

Food: The food and feeding habits of hilsa vary with the time of the day, season, size of fish, ecological conditions and food substances present in the habitat (Hynes, 1950). Juveniles of hilsa are plankton feeders; grazing on zooplankton at higher rate for five to six months in fresh water. They change their food habit based on age and seasonal variability and slowly transform to phytoplankton feeding habit. Hilsa prefers to reside in the brackish water region due to the presence of sub surface oxygen, relatively low salinity, strong tidal flow, high turbidity, heavy siltation and rich growth of plankton (Pillay and Rosa, 1963). During maturation, hilsa minimize their food intake and stop feeding during spawning migration. In general, hilsa is a plankton feeder and does not show any selectivity in feeding with its closely set sieve like gill rakers (Hora, 1938; 1940). Being a filter feeder, it takes food particles while swimming in the water. Hence, occurrence of different food material in the gut varies based on the season and location. Young hilsa between 20 mm and 40 mm in length feed mostly on diatoms and sparingly on copepods, daphnia and ostracods. Older specimens, up to 100 mm in length were found to feed on smaller crustaceans and also on insects, chironomid larvae, etc. According to Hora and Nair (1940a), algae constituted the bulk of the food eaten during February-March, while diatoms formed the main item during March-April. Major group of food items recorded from the gut of hilsa include crustaceans (particularly copepods), diatoms, green and blue algae, organic detritus, mud and sand particles (Hora, 1938; Hora and Nair 1940a; Chacko and Ganapati, 1949; Pillay and Rao, 1963; Halder, 1968). Jones and Sujansinghani (1951) inferred that the species does not exhibit any selectivity in feeding as far as the different items of plankton are concerned. Stomach content analysis of fry, juvenile and adult hilsa revealed that copepods are the most important food items consumed by the fish of all sizes at all times of the year (De and Datta, 1990b) carried out stomach content analysis on hilsa and observed that copepods are the most important food item consumed by the fish of all sizes at all times of the year. They also reported that the fry and juvenile hilsa mainly feed on copepods while the stomach content analysis of adult hilsa showed considerable amount of organic matter along with the copepods. The other notable difference according to De and Datta (1990b) in the food items is the uniform presence of minute organisms like diatoms, rotifers, green algae and protozoans in the stomach of adult while these minute organisms are either totally absent in the stomachs of fry or are poorly present in the stomachs of juveniles. Hora (1938) recorded mostly diatoms and sparingly crustaceans in the gut of young hilsa between 20 and 40 mm in length, while in slightly larger specimens, up to 100 mm, mostly smaller crustaceans, insects and polyzoa occurred. The mean percentage composition of food of adult and young hilsa in the river Godavari indicated that organic debris, diatoms and crustaceans form the major constituents of food of both adults as well as young hilsa (Pillay and Rao, 1963). Organic debris along with sand grains forms a dominant constituent of the gut of both adult as well as young hilsa throughout the year. Hora and Nair (1940), based on presence of sand grains in stomach of young hilsa, inferred that the fish might be bottom feeding in habit; suspended particles present in the turbid water current also might be the reason for the presence of mud in the gut content of hilsa. Jones and Menon (1951) reported that the larval hilsa feed mainly of diatoms and copepods. According to them, with further growth, the juvenile fish turn to feed on a variety of other planktonic organisms. Larger quantities of sand grains have been found in the stomachs of spent hilsa (Pillay, 1958b). Halder (1968) described the food of *T. ilisha* in the size range 120 to 160 mm and from 180 to 200 mm from Hooghly estuarine system consisting of *Cyclotella* sp., *Melosira* sp., *Gyrosigma* sp., *Microcystis* sp., *Aphanocapsa* sp., *Oscillatoria* sp. and *Spirogyra* sp. Rajyalakshmi (1973) reported that mostly empty guts in the adults during monsoon in river Godavari, while juveniles showed fully fed guts, predominantly with copepods and rotifers. Islam (1974) and Swarup (1959) reported that sexually mature *T. ilisha* feeds on diatom genus *Melosira* (98%) during the spawning migration. Das (1985) worked in Bangladesh and Pakistan and reported that *T. ilisha* is a planktivore, exploiting both zooplankton and phytoplankton. In the young stages, the diet of hilsa dominated by diatoms and as the fish grew the composition of the diet shifted towards crustacean items, especially copepods; spent fish are believed to be benthic feeders as considerable quantity of mud and sand is ingested. On the other hand, Al-Nasiri and Mukhtar (1988) while working on *T. ilisha* from

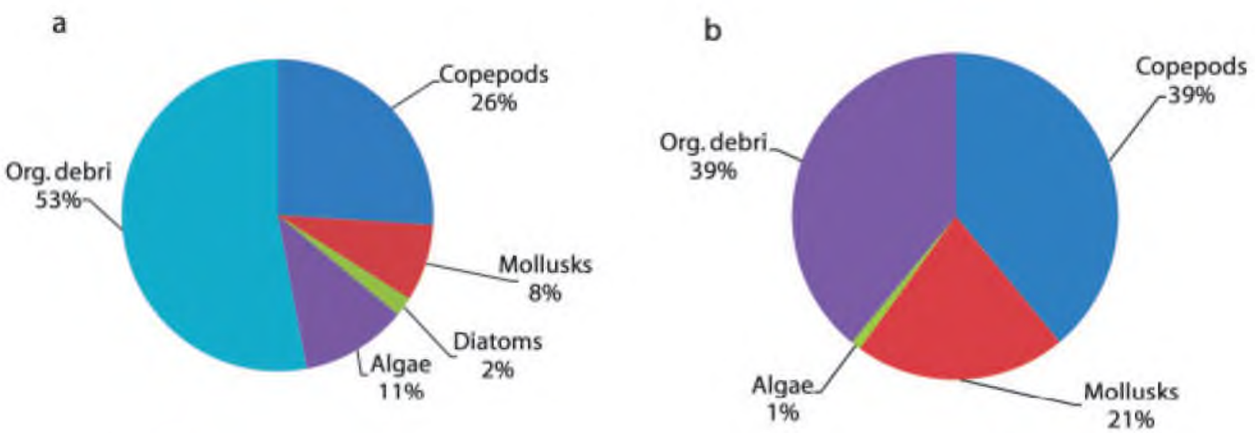


Fig. 15. Compositions of stomach content of (a) young and (b) adult hilsa. Source: Pillay and Rao (1963)

Ashar Canal, Basrah (Shatt al-Arab River), Iraq, concluded that the main food of this species is zooplankton (mainly copepods (*Cyclops*) and phytoplankton such as dinoflagellates and diatoms. The main food items were *Cyclotella, Planktosphaeria, Oscillatoria,* and *Cyclops*. It was also found that the average volume of food in each stomach is more in small fishes than in large ones. Pillay and Rao (1963) studied the gut content of hilsa and found organic debris (51.58%), sand grains (10.32%), diatoms (2.10%), protozoans, rotifers, crustaceans, mollusks (7.85%) and copepods (25.82%) as the major food components, while the major components of stomach content of adult hilsa were organic debris (32.0%), sand grains (0.8%), diatoms, protozoans, rotifers, crustaceans, mollusks (17.5%), and copepods (31.7%) as shown in Fig. 15 a and b.

Hora and Nair (1940a) in their study in Bangladesh rivers found that hilsa feed on filamentous algae, diatoms and copepods. The food of the young individuals consisted mainly of organic detritus (48.56%), copepods (25.82%), algae (10.32%), mollusk larvae (7.85%), mysids (5.34%) and diatoms (2.10%). Pillay and Rao (1963) studied the stomach content of young and adult hilsa in Godavari River during January to December 1961. The main genera of algae found in the guts were *Pediastrum* sp., *Oscillatoria* sp. and *Spirogyra* sp. Besides *Microcystis* sp., *Ankistrodesmus* sp., *Closterium* sp., *Cosmarium* sp., *Merismopaedia* sp., *Coelastrum* sp., *Sphaeropzosma* sp., *Pleodorina* sp., *Tetraspora* sp., *Apiocystis* sp., *Staurastrum* sp. and *Geastrum* sp. were also recorded. The most important diatoms were *Coscinodiscus* sp., *Cyclotella* sp., *Thalassiothrix* sp., *Synedra* sp., *Thalassionema* sp., *Biddulphia* sp., *Rhizosolenia* sp., *Pleurosigma* sp., *Gyrosigma* sp., *Campylodiscus* sp., *Diploneis* sp., *Tropedoneis* sp., *Surirella* sp., *Navicula* sp., *Bacteriastrum* sp., *Chaetoceros* sp., *Ditylum* sp., *Lithodesmium* sp., *Nitzschia* sp., *Pinnularia* sp., *Mastogloaea* sp., *Cocconema* sp., *Melosira* sp., *Fragilaria* sp., *Stauroneis* sp., *Caloneis* sp., *Cymbella* sp., *Corethron* sp., *Amphora* sp. and *Stephanopyxis* sp. Rajyalakshmi (1973) reported that copepods formed the bulk of crustaceans in the gut. Nauplii of copepods were also present in the guts during the major part of the year. Cladocerans especially *Bosmina* sp., *Moina* sp. and *Daphnia* sp. were dominant in guts. Among the mollusks only larval bivalves and larval gastropods have been found in the gut contents (Pillay and Rao, 1963). Narejo et al. (2005) added that the diet of *T. ilisha* of ring dam (up-streams) of river Indus was mainly composed of three groups of phytoplankton (93%), other plant materials (3.04%) and debri (3.96%). Among phytoplankton, Bacillariophcea (*Gyrosigma, Cyclotella* and *Cymbella*) formed 70.4%; Cyanophyceae (*Oscillatoria, Lyngbya, Microcystis* and *Chroococus)* formed 16.6% and Chlorophyceae formed (*Oedogonium, Rhizoclonium* and *Scendesmus)* 9.04% and debris 3.96%.

Halder (1968) recorded marked variation in the intensity of feeding in both young and adult hilsa over the year. Ramakrishnaiah (1972) also reported monthly variations of stomach contents with copepods occurring throughout the year in varying quantities, which was predominant in April, July, August and September. Mysids in post-monsoon and winter months and were dominant during November to January. Mollusk larvae were frequent in summer and winter months. Sand and mud were present in small quantities during monsoon months. Chacko and Ganapati (1949) reported that the fish feed at all depths. Stomach content analysis of 150 hilsa from the Godavari river by Chacko and Ganapati (1949) recorded empty stomachs or traces of food in gut during April to July. Feeding intensity also showed seasonal variation. For example, increased feeding activity was observed during winter months when there is a plankton bloom. On the contrary, during monsoon months which form the main breeding season of the fish and a period of lesser plankton growth in river, the feeding intensity was low. Hence, the probability of low intensity of feeding during spawning season may be due to scarcity of food organisms in the river (Pillay and Rao, 1963). Shafi et al., 1977a) recorded that the juveniles were voracious eaters. From the occurrence of large number of empty stomachs of adult hilsa, Southwell and Prashad (1918) inferred that adult hilsa do not feed while ascending the rivers. Bhimachar (1955) reported that the intensity of feeding increases in spent hilsa in the river Hooghly while Swarup (1959) found that the feeding of spent hilsa decreases immediately after spawning in Ganga at Allahabad. Pillay and Rao (1963) inferred that the feeding intensity of hilsa depends on the abundance of planktonic organisms in the environment and opined that there appears to be hardly any cessation of feeding during spawning. This finding was supported by Islam (1974). The juveniles are voracious feeders and sand particles are comparatively more abundant in their stomachs. During February and March, algae constituted the bulk of the food eaten by the fish, while during March-April, diatoms formed the main item. The species is mainly a sight feeder as the fish possesses well developed optic lobes and since olfactory lobes are reduced, the fish is supposed to have poor gustatory sense (Saxena, 1970). The nature of food items indicated that young hilsa feed mainly from surface and column of water body, whereas the presence of decayed organic matter, diatoms, sand and mud along with copepods strongly suggests the bottom and column feeding habits of adult hilsa during upstream migration. Jafri et al. (1999) studied food and feeding habit of land-locked populations of *T. ilisha* in Keenjhar lake (Sindh) and reported that the guts had abundance of *Bosmina longirostris*, *Cyclops* sp. and *Microcystis* sp.

REPRODUCTIVE BIOLOGY

Size at maturity

There are conflicting reports on the size at first maturity of the species. Jones and Menon (1951), based on their observations in the Hooghly, the Mahanadi and Chilika lake, concluded that males become mature when 21.6-25.4 cm in length and suggested they were over one year old; females become mature in the second year when 26.7-30.5 cm long. However, Pillay (1958b) found still smaller sizes in the Hooghly river at maturity; some males matured at 16-17 cm and females at 19-20 cm in total length when they are both about 1.5 years old. Some workers have expressed the view that males mature earlier than females, but there was no evidence to prove it (Pillay and Rosa, 1963). Mathur (1964) reported that 50% of the females mature at 35 cm, while the smallest size at maturity was 33 cm in Ganga at Allahabad and 31 cm at Varanasi. He also recorded that males mature at a length of about 20 cm in the upper stretches of Hooghly. De (1980) reported that female reach maturity at the size of 32 cm. The

Table 7. The size at maturity of hilsa estimated by various workers

Minimum size at maturity		Water body	Author (s)
Male (mm)	Female (mm)		
216-254	267-305	Hooghly, Chilika and Mahanadi	Jones and Menon (1951)
160-170	190-200	Hooghly estuary	Pillay (1958b)
172	186	Chilika lake	Ramakrishnaiah (1972)
280	382	Godavari river	Chacko and Krishnamurthy (1950)
300	356	Godavari river	Chacko and Ganapati (1949)
360	420-430	Godavari	Rajyalakshmi (1973)
	266	Narmada river	Karamchandani (1961)
256	370	Godavari	Pillay and Rao (1963)
	341	Hooghly estuary	De (1980; 1986)
200	350	Ganga river	Mathur (1964)
	330	Ganga at Allahabad	Mathur (1964)
	310	Ganga at Varanasi	Mathur (1964)
175-300	200-300	Chilika lake	Jhingran and Natrajan (1969)
210	320	Meghna (Bangladesh waters)	Shafi et al. (1978b)
400	400	Bangladesh waters	Dunn (1982)
	415	Kuwait waters	Al-Baz (2001)
250	330	Shatt Al-Arab river (Iraq)	Hussain et al. (1994)

smallest mature male hilsa observed in the Godavari was 25.6 cm while the smallest mature female was 37.0 cm long (Pillay and Rao, 1963). Through length frequency studies, it was concluded that the modal size of 35.5 cm represent fish aged 1^+ year. Dunn (1982) reported that almost all reproducing hilsa were at the length of about 40 cm. Stages of maturity of female gonads have been studied by Pillay and Rao (1963), Mathur (1964) and De (1986), revealing that females below 300 mm size group hardly took part in spawning activity. According to De (1980, 1986), the smallest mature female observed in the Hooghly estuary was around 341 mm length and 550 g weight, that are comparable with the hilsa from Allahabad and Varanasi and also Godavari and concluded that females below 300 mm size group do not take part in spawning. The sizes at maturity of the fish reported by various authors from different river systems are shown in Table 7.

Sex ratio

The females are distinguished with bulging abdomen when gravid and the male with oozing milt from genital opening when pressed, during breeding season. The species is heterosexual, though one instance of herrnaphroditism has been reported (Chacko and Krishnamurthy, 1949). The females, due to faster growth rate, attain larger sizes than the males (Pillay, 1958b; Pillay and Rosa, 1963; Jhingran and Natarajan,

Table 8. Sex-ratio of hilsa as reported by different author (s)

Location	Ratio (Male: Female)	Author(s)
Godavari	1:9	Chacko and Ganapati (1949)
Hooghly	1:1 (approx)	Jones and Menon (1951)
Ganga	1:1	Jhingran (1957)
Ganga	1:1 (approx)	Pillay (1958b)
Ganga	2:1	Swarup (1958)
Indian water	1:1.53	Pillay and Rao (1963)
Ganga	1:1	Mathur (1964)
Indus	1:1	Quereshi (1968a)
Chilika	1:1	Ramkrishnaiah (1972)
Meghna	2:1	Shafi et al. (1978a)
Ganga	1:1	De (1986)
Bay of Bengal (Chittagang)	1:1.08	Islam, et al. (1987)
Bay of Bengal (Cox's Bazar)	1:1.8	Islam, et al. (1987)
Bay of Bengal (Khepupara)	1:0.42	Islam, et al. (1987)
Bay of Bengal (Chandpur)	1:1.08	Islam, et al. (1987)
Indus	3:1	Narejo, et al. (1999)
Bangladesh	1:5.09	Amin, et al. (2005)
Hooghly	38:62	Bhaumik and Sharma (2011)
Indus	1.1:1	Panhwar, et al. (2011)
Persian Gulf and Rivers of Khouzestan Province of Iran	1:2	Rumiani, et al (2014)

1966; Quddus, 1982). Shafi et al. (1977b) have observed that the body of females is broader and the girth comparatively larger. They have also mentioned that the urino-genital opening of the gravid female is flat, but narrower in the case of males, where the papillae are comparatively prominent. Many workers found the sex ratio in natural populations to be significantly different from that of the theoretically expected ratio 1:1, although this was not always the case (Table 8). Size wise distribution of sexes in Bangladesh waters revealed higher percentage of females in the size group above 40 cm SL (Mazid, 1998).

Gonad development

Several authors have observed different stages of gonadal maturation of hilsa. The maturation of the gonads, probably depends on temperature and it is observed that gonadal activity is inhibited by very high and very low temperatures (Nair, 1958). The different maturity stages of gonads described by different authors are given in the Tables (9, 10 and 11).

Table 9. Maturity stages of male and female hilsa (*T. ilisha*) reorganised after Pillay and Rao (1963)

Maturity Stage	Characteristics	
	Female	Male
Stage I (Immature)	Ovaries thin and extending to about half the length of body cavity. No ova visible to the naked eye. When teased under the microscope, oocytes can be seen, transparent, with nucleus and no yolk granules. Diameter of ova less than 50 µm.	Testes very thin ribbon like, whitish, extending to about 0.75 of body cavity. Strands of tissue with spematogonia can be distinguished when teased under microscope.
Stage II (Maturing)	Ovaries about 5 mm in diameter, length slightly more than half of body cavity. Ova are not visible to the naked eye, but faintly discernible when ovary is teased. Ova appear transparent with a few yolk granules in larger ones. Diameter of maturing groups of ova up to 150 µm.	Testes slightly broader and thicker than Stage I.
Stage III (Maturing)	Ovary about 7.5 mm thick, occupying more than half of body cavity, ova yolked and visible to naked eye. When teased under the microscope ova are opaque and <300 µm.	Testes larger, but not yet extend to 0.5 the length of the body cavity. Spermatogonia discernible under the microscope.
Stage IV (Maturing)	Ovaries occupy more than half of the body cavity; they are much thicker, yellow in colour, over 15 mm in thickness. Ova opaque and less than 300 µm.	Testes extend about half of the abdominal cavity, appreciably larger and white in colour and soft in texture. Spermatocytes are seen under the microscope and a few spermatids.
Stage V (Maturing)	Ovaries occupy whole length of body cavity, much thicker and granular and yellow in colour. Ova about 550 µ m.	Testes occupy almost whole of the body cavity, whitish and soft. Large number of spermatids is in clusters.
Stage VI (Mature)	Ovaries occupy whole length of body cavity and have maximum thickness. Large transparent ova that ooze out at slightest pressure. Diameter of ripe ova up to 850 m or slightly more.	Testes broader and thicker than previous stage, pinkish white in colour and soft in texture. Large number of clusters of tailed sperms visible. Spermatids are also seen in good number. Vas deference is full of milt which may come out with little pressure.
Stage VII (Partly spent spawning in progress)	Ovary smaller in size than that of at Stage VI, less firm to the touch, contain a few large ova of diameter of about 850 m, which may be partly or fully transparent, but majority of ova nearer to 550 µm.	Testes less thick and soft compared to the previous stage and extend only to about 0.5 of abdominal cavity. Full of sper-matozoa and spermatids, the latter in fewer numbers. Vas deference with large number of spermatozoa.
Stage VIII (Spent)	Ovary considerably smaller, reddish, flaccid, fibrous, with a few large ova scattered in between connective tissue. Majority of ova below 200 µm.	Testes very thin and ribbon like. A few spermatozoa may be present in vas deference. Spermatogonia are present in good numbers.

Table 10. Ovarian characteristics of hilsa by macroscopic examination.

Stage	Characteristic
Nearly Ripe	Ovaries paired, elongated, small and purple coloured. Most of the oocytes are partially yolked and few oocytes are in primary growth stage and cortical alveoli present.
Fully developed	Ovaries median to large, yellowish. Most of the oocytes are advanced, yolked with small oil vacuole in cytoplasm and rarely primary growth oocytes are present.
Running ripe	Ovaries large to very large, deep yellow, more or less cylindrical, extended completely in the body cavity. Most of the oocytes are advanced, yolked with large oil vacuole present and postovulatory follicles are occasionally present.
Partially spent	Ovaries large, light yellowish. Mostly oocytes are present. Primary growth oocytes are rarely present and postovulatory oocytes are occasionally present.
Spent	Ovaries small, dark purple with presence of primary growth oocytes, atretic oocytes and large amount of degenerated tissue (macrophage aggregates) and appearance of some postovulatory follicles.

Source : Lowerre Barbieri et al. 1996; Panhwar et al. 2011

Table 11. Testicular characteristics of hilsa by macroscopic examination

Stage	Characteristic
Developing	Testes paired, light pinkish and spermatocytes are generally present with few number of spermatids.
Nearly ripe	Testes larger than developing stage, light cream in color and spermatids are generally present with few spermatocytes and few spermatozoa were also present.
Ripe	Testes large, more or less cylindrical, whitish, filled with a creamy colored fluid and the lumen is densely packed with spermatocytes.
Partially spent	Testes small to large, light purple with few spermatozoa and large amount of connective tissue.
Spent	Testes very small with contracted follicles, colorless and contracted with abundance of connective tissue and very few residual spermatozoa.

Source : Lowerre Barbieri et al. 1996; Panhwar et al. 2011

Mature ovary of hilsa

Fecundity

Fecundity is expressed as the number of eggs present in the ovary that are expected to be laid. It is an important aspect of the reproductive biology and assesses the potential stock of any fish (Akter et al., 2007). The variation of fecundity is very common in fish (Doha and Hye, 1970) and the number of eggs produced by an individual female is dependent on various factors like size, age, condition and type of species of the sample (Lagler et al., 1967). Depending upon the size of hilsa, the fecundity varied from 250000 to 2917000 as reported by different

Table 12. Fecundity of hilsa as reported by various workers

Location	Size	Fecundity (No.)	Author (s)
Godavari estuary	910 g	1282100	Chacko and Ganapati (1949)
Narmada	2100 g	1864000	Kulkarni (1950)
Hooghly estuary	253-481 mm	250000-1600000	Pillay (1958b)
Ganga and Yamuna (near Allahabad)	315-506 mm	289000-1168622	Swarup (1961)
Godavari estuary	401-548 mm	400000-1300000	Pillay and Rao (1963)
Ganga (near Allahabad and Varanasi)	310-436 mm	316316-1840179	Mathur (1964)
Indus	300-600 mm	755000-2917000	Bhuyian and Talbot (1968)
Indus	358-550 mm 765-2,892 g	755000-2917000	Islam and Talbot (1968)
Indus	Not mentioned	80000-2000000	Qureshi (1968a)
Padma and Meghna	275-483 mm	90000-2000000	Qureshi (1968a)
Padma	273-420 mm (Fork length)	348318-1465969	Doha and Hye (1970)
Chilika lake	353-515 mm	390379-1120304	Ramkrishnaiah (1972)
Meghna	380-520 mm	380000-1820000	Shafi et al. (1978b)
Padma and Meghna	330-510 mm 320-490 mm	600000-1500000 400000-670000	Quddus (1982)
Padma and Meghna	342-520mm (Broad variety) 260-470 mm	660000-1547000 399000-670000	Quddus et al. (1984b)
Hooghly estuary	343-522 mm	373120-1475676	De (1986)
Bay of Bengal near Chittagong	325 to 492 mm; 425-1600 gm	375000 -1423000	Moula (1989)
Diamond Harbour, Fraser gunj and Digha in West Bengal and Talsari in Orissa	370-540 mm	467100 - 1369500	Reuben et al. (1992)
Meghna	267-523 mm 275-l715 g	226000-1390000	Moula (1992)
Khuozestan river, Kuwait	380-500 mm	37482-1954144	Marammazi et al. (1998)
Indus	201-408 mm	64608-1153383	Narejo et al. (1998)
Meghna	287-523 mm	226000-1931000	Rahman et al. (1998)
Padma and Meghna	171-415 mm	108500-1993846	Blaber et al. (2001)
Bangladesh waters	2.1 kg	1864000	Shafi and Quddus (2001)
Padma	280-445 mm	144000-230000	Haldar (2004)
Padma	390-510 mm	1030951-1940620	Saifullah et al. (2004)
Meghna	240-480 mm	112554-950625	BFRI (2007)
Padma	350-557 mm	558700-1867000	Akter et al. (2007)
Indus	210-350 mm	87 267-614482	Panhwar et al. (2011)
Hooghly-Bhagirathi	208-475 mm	44002-1554894	Bhaumik and Sharma (2012)
Hooghly estuary	573 mm	2134721	Sandhya et al. (2016)

workers (Table 12). De (1986) reported that average number of mature eggs per gram of body weight ranged from 502 to 1350 with an average of 1190, while the average number of mature eggs per gram of ovary weight was 7460. Sandhya et al. (2016) reported the highest fecundity of hilsa from Hooghly estuary.

Spawning season

The spawning season of hilsa has been reported to vary from a few months to year-round, depending on the ecosystem (Table 13). The peak spawning period for hilsa is monsoon and winter, but they may spawn in other seasons and even throughout the year (Raja, 1985). Pillay (1958a) found two

Table 13. Spawning season of hilsa in different water bodies

Location	Major peak	Minor peak	Author
Ganga	September to December	July	Motwani et al. (1957)
Hooghly (1941)	July-August	May	Hora and Nair (1940a); Hora
Hooghly	December-January	–	Jones and Menon (1951)
Hooghly	July-November	January-March	Pillay (1958b)
Hooghly	August, October	–	Chandra (1962)
Hooghly	February-March, July-August, October- November	All other months	Bhanot (1973)
Hooghly	January-February	–	Sujansingani (1957)
Hooghly	September-October	–	De and Datta (1990)
Hooghly-Bhagirathi	July-October, February-March	All other months	Bhaumik and Sharma (2012)
Hooghly	September-October	–	De and Datta (1990a)
Narmada	June-July, September	–	Kulkarni (1950)
Narmada	June-July, September	–	Karamchandani (1961)
Saurastra coast	April-May	–	Pillay (1964)
Chilika	August-September	July	Ramakrishnaiah (1972)
Daya river	Monsoon		Jones and Sujansingani (1951)
Godavari	August-November	February-April	Pillay and Rao (1963)
Godavari	July- November	–	Chacko and Ganapati (1949)
Brahmaputra	May-July	–	Rao and Pathak (1972)
Indus river	August, October, July	May, June and September	Panhwar et al. (2011)
Bangladesh water	Monsoon	All other months	Ahmed (1954)
Bangladesh water	October-November	All other months	Islam et al. (1987)
Bangladesh water	July-October	January-March	Quddus (1983)
Bangladesh water	Monsoon and Winter	All other months	Raja (1985)
Meghna	January-March, July-October	–	Shafi et al. (1978b)
Kuwait water	May-July	–	Al-baz and Grove (1995)
Rivers of Khouzestan Province of Iran	May-August	–	Rumiani et al (2014)

breeding seasons, suggesting a bimodal annual spawning cycle of the species. Motwani et al. (1957) stated the first spawning period as September-December and the second as July. These observations were confirmed by Pillay and Rao (1963), but Bhaumik and Sharma (2012) reported the productive months as in July-October and February-March.

Based on the histological studies of gonads in different months of the year, Nair (1958) reported that spermatogenesis and oogenesis start by the end of January and reach peak in March, but majority of ova undergo resorption and atresia. While, De (1980, 1986) reported that the species spawn once in a year with definite spawning season and the matured group of ova shed in a short duration. The prolonged availability of hilsa seed in Hooghly during July-August to March-April with a peak in October and November suggests that the process of maturation of ovaries among the females of ascending shoals is spread over a prolonged period of time (De et al., 1994). Similar prolonged period of spawning in hilsa was also recorded from river Godavari (Rao, 1969). Nair (1958) reported that spermatogenesis and oogenesis processes of hilsa are fully active when the temperature rise to 25 °C, but temperature of 30 °C inhibits gonad activities. While, De (1980 and1986), reported that temperature between 24 °C to 29 °C has been found to be optimum for spawning.

Spawning ground

There has been conflicting reports on the probable breeding ground of hilsa, with several workers reporting different breeding grounds; most of which in freshwater stretches of rivers and some even indicated that the fish might breed in seawater. The fish migrates from salt water environment to freshwater environment for breeding (Day, 1879). According to Southwell and Prashad (1918), hilsa breeds when environmental conditions such as temperature, weather and other factors are suitable during rains and no fixed breeding grounds exist. Pillay and Rao (1963) observed spawning activity in two or three branches of river Godavari about 20-25 miles away from the sea, at the zone below the anicut at Dowlaiswaram to a distance of nearly 35 to 40 miles downstream. They noticed that hilsa also breeds above the anicut when the fish are able to migrate above Dowlaiswaram during high flood and when the flood subsidies the juveniles are available in the upper stretches, which can be considered as an evidence of hilsa breeding in those regions. Qureshi (1968b) reported that hilsa spawns in freshwater region of rivers, which is 85-170 km away from the sea. Pillay (1964) observed maturing (stage-V), mature (stage-VI) and partially spent (stage-VII) male and female hilsa in the sea of Saurastra coast during April and May in 1957-58, which indicated that hilsa also breeds at this place. But Reuben et al. (1992) opined that hilsa does not breed in sea. Jones and Sujansingani (1951) reported that, in the lower reaches of the Daya river is breeding ground of hilsa of Chilika lake and due to the availability of larvae and eggs at the mouth of Daya river and the surrounding areas in the eastern shore of the northern sector Kowtal (1967, 1976) also suggested this region as a breeding ground of hilsa. The stretch of river Hooghly near Palta Waterworks, Barrackpore, West Bengal was denoted as one of the spawning grounds of the fish (Hora, 1938; Hora and Nair, 1940a; Jones and Menon, 1951). The river Hooghly at Bagh Bazar in Kolkata was earlier considered as the lower limit of the spawning ground of hilsa (Pillay, 1958b). Both Chandra (1962) and Bhanot (1973) also reported that the freshwater zone of river Hooghly as the breeding ground of this fish. The stretch of river Ganga between Patna and Allahabad was reported as spawning area of hilsa (Motwani et al., 1957) before commissioning of the Farakka barrage. Bhaumik and Sharma (2012) reported that there are three spawning grounds of hilsa in river Hooghly. First is between Lalbagh to Farakka (Lat. 24° 05.243' N, Long. 88° 27.942' E and Lat. 24° 27.253' N, Long. 88° 54.470' E), the second is between Hooghly Ghat to Kalna (Lat. 22° 25.115' N, Long. 88° 23.826' E) and the third is between Diamond Harbor and Godakhali (Lat. 22° 10.182' N, Long. 88° 12.034' E and Lat. 22° 24.284' N, Long. 88° 08.548' E). Hossain et al. (2014) applied geo-referenced habitat database to determine spawning habitat suitability index of hilsa in Bangladesh waters and reported that only 6% (1851 km^2) area is most suitable consisting of the rivers Meghna, Shahbazpur, Tetulia and Ander Manik as well as the channel of Sandwip island. Whereas, 20% (5996 km^2) area including river, estuary and near shore water bodies are moderately suitable and the offshore deep waters occupying 73% (21637 km^2) area is least suitable, out of the total area of 29484 km^2 investigated. From the foregoing discussion, it appears that the fish does not have any permanent breeding ground and spawns in areas where the environmental conditions are conducive.

Spawning frequency

Pillay (1958b) observed that very small proportion of the ova are shed at each time of spawning and the spent fish is available only during the end of the breeding season in Hooghly and Ganga rivers. He concluded that hilsa breed intermittently for several time during the breeding season, otherwise the spent fish could be obtained throughout the seasons as a result of only one spawning in a season, which was supported by Hora and Nair (1940a) and Hora (1941). Swarup (1959) reported that in river Ganga and Yamuna, at Allahabad, hilsa spawns several times in the breeding season. In river Meghna in Bangladesh, hilsa spawns intermittently throughout the year (Shafi et al., 1978b). Fractional spawning was also reported by Pillay and Rao (1963), in the river Godavari based on occurrence of partly spent ovaries and one modal size group of eggs ripening towards maturity. Mathur (1964) reported multiple modes among the already differentiated ova in the advanced stages of maturity. According to him these modal groups are shed in batches. He also did not rule out the possibility of resorption of some of the well-advanced ova as that large percentage of advanced ova was still present in partly spent ovaries. There is also possibility of unshed ova being carried over to the next spawning season (Mathur, 1964). Thus, there is fractional and multiple spawning of the same fish within the breeding season, while Ramakrishnaiah (1972) and De (1980) argued for single spawning by individual hilsa in the breeding season in the Chilika Lake and river Hooghly, respectively. Zohre et al. (2015) studied histological changes in oocytes of hilsa from Persian gulf and associated rivers and thier study indicated that hilsa is a synchronous fish species with most of the ovarian follicles at the same phase of development in ripe ovaries.

Fertilization

The species is polygamous and fertilization is external (Pillay, 1958b). After fertilization, the larvae hatch out and drift by the current to the nursery grounds. The freshly laid eggs with vitelline material after fertilization, start absorbing water and swells up. They sink in still water but in slight current the eggs buoyed up and drifted easily; appearing to be pelagic (Kulkarni, 1950). Eggs are pale yellow in color,

Table 14. Diameter of fertilized and unfertilized eggs of hilsa obtained from different rivers as reported by different authors

Author	Location	Egg dia. (mm) Unfertilized	Egg dia. (mm) Fertilized
Southwell and Prashad (1918)		0.8	1.8
Kulkarni (1950)	Narmada	1.3 to 1.5	2.1-2.3
Jones and Menon (1951)	Hooghly	0.70-0.75	-
Pillay (1958b)	Hooghly	0.89	-
Swarup (1961)		0.6-0.9	-
Pillay and Rao (1963)	Godavari	0.85	-
Mathur (1964)	Ganga	0.76-0.86	-
Quereshi (1968a)	Banladesh	0.7	-
Shafi et al. (1978b)	Banladesh	0.735	-
De (1980)		1.0	-
De and Sen (1986)	Ganga	0.76-0.87	1.95-2.10
Akter et al. (2007)	Padma	0.68-0.87	-
Sandhya et al. (2016)	Hooghly	0.56 - 0.84	-

oily, transparent and demersal in character (Qureshi, 1968a). Jones and Menon (1951) found that the egg membrane is elastic and vitelline space is wide; the segmented yolk has numerous oil globules of varying sizes, which aggregate to form a large and conspicuous globule later on. Kulkarni (1950) and Motwani et al. (1957) reported that the egg possess double layered membrane. The characteristics of unfertilized and fertilized eggs were studied by De and Sen (1986). They found that unfertilized eggs were spherical, demersal in still water, transparent and loaded with large amount of yolk mass, which is light yellow in color and pre-vitelline space is 0.07-0.08 mm in width. Immediately after fertilization, the eggs started to swell and color changed to greenish yellow and after 15-20 minutes it became transparent. Fertilized eggs were soft, smooth, non-adhesive, spherical and buoyed up and drifted easily with slight current. Malhotra *et al.* (1969) also reported that the fertilized eggs turned transparent in 15 minutes. The diameters of fertilized and unfertilized eggs of hilsa obtained from different rivers as reported by different authors are listed in Table 14.

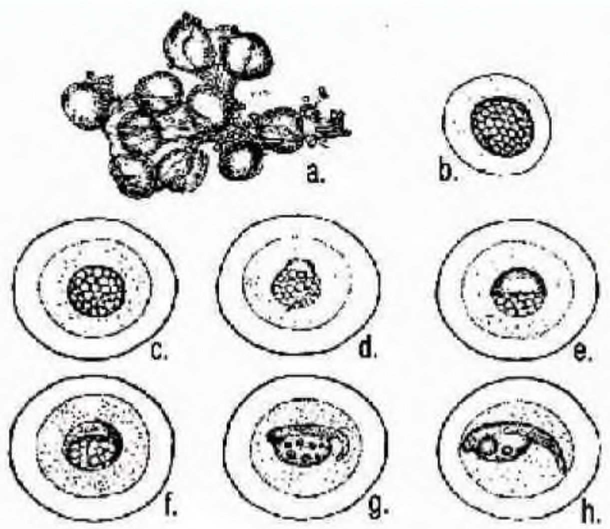


Fig. 16. Development stages of fertilized egg (a) Piece of an ovary showing fully developed and undeveloped ova along with mesentery, (b) Ripe unfertilized ovum, (c) A fertilized egg after absorption of water, (d) Blasto-disc formation after half an hour of fertilization, (e) A stage four hours after fertilization, (f) Formation of embryonic shield after eight hours, (g) Embryo formation 12 hours after fertilization, (h) 17 hours later the embryo is ready to break out from the egg. Source: Kulkarni (1950)

Embryonic development

Freshly fertilized eggs are 1.3-1.5 mm in diameter, with semi fluid viteline material. After water absorption the eggs dilate up to 2.1-2.3 mm in diameter. Various stages of development of fertilized egg are shown in Fig. 16, as adopted from Kulkarni (1950).

Fertilization

↓ **30 minutes**

Completion of movement of protoplasm towards the lower pole and blasto-disc is formed (Fig. 16d)

↓ **4 hour**

Segmentation of blastula, development of a cap of cells covering half of the oil globule (Fig. 16e)

↓ **4 hour**

Apprarence of embryonic shield (Fig. 16f)

↓ **3.5 hour**

Differentiation of head and tail region (Fig. 16g)

↓ **3 hour**

Contraction of the body of the embryo

↓ **2 hour**

Embryo twitching movement inside the egg (Fig. 16h)

↓ **1 hour**

Larvae break out of the egg membrane

Fig. 17. Progressive growth of fertilized egg. Source: Kulkarni (1950)

The development of the egg starts immediately after fertilization. The details of progressive growth of fertilized egg are given in the flowing diagram (Fig. 17) as described by Kulkarni (1950).

De (1986) and De and Sen (1986) reported that hatching commence in 18 hours after fertilization and complete in 21 hours. Detailed stages of embryonic development of the fish are given in Fig. 18.

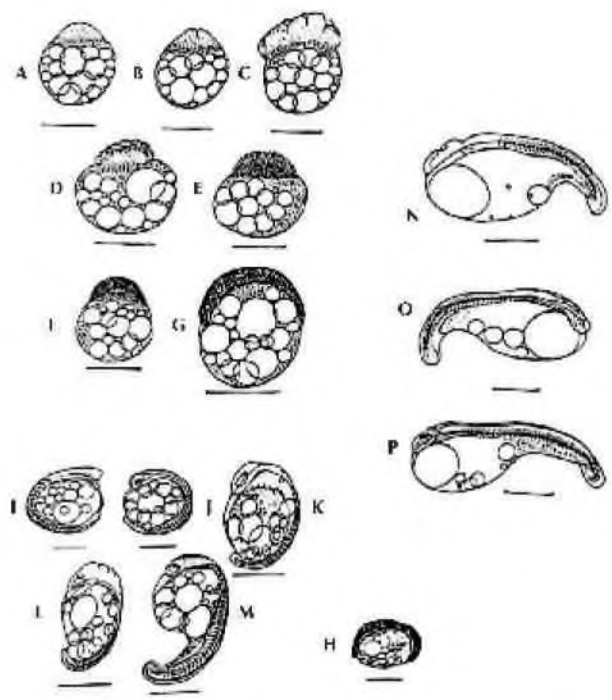


Fig. 18. Detailed stages of embryonic development of hilsa. (A) Fertilized eggs, (B) Two celled stage, (C) Eight celled stage, (D) 16 celled stage, (E) Blastula stage, (F) Morula stage, (G) Gastrula stage (H) Yolk plug stage, (I) 18 Myotome stage, (J) 20 Myotome stage, (K) Auditory capsule formed, (L) 28 Myotome stage, (M) Embryo showing twitching movement, (N) Oil globules reduced in number, (O) Just before hatching, (P) Immediate after hatching. Source: Kulkarni (1950)

Table 15. Temperature, egg incubation period and length of the newly hatched larvae as described by various authors

Authors	Temperature (°C)	Incubation period (hours)	Length (mm)
Kulkarni (1950)	27.5- 28.5	18-26 (in Narmada river)	3.1
Jones and Menon (1951)	23.0	23-26	2.3
Motwani et al. (1957)	Not mentioned	24-28	2.5-2.55
Karamchandani (1961)	-	-	2.65 (2.4-3.0)
Panicker et al. (1982)	Not mentioned	20 (Fertilized eggs obtained through stripping of fishes from Narmada river)	–
De and Sen (1986)	24.0- 27.0	16-20 (Ganga river at Farakka)	2.41 (2.37-2.44)

Larval development

Experiments conducted by different workers on larval growth revealed that there is difference in egg incubation time, depending on the temperature and variation in length of newly hatched larvae. De and Sen (1986) recorded the average length of 1-day, 2-day, 3-day, 4-day and 5-day old larvae as 3.75 mm, 3.97 mm (3.95-4.00 mm), 4.15 mm, 4.42 mm and 5.12 mm respectively. The incubation period and length of hatched out larvae as reported by various workers are given in Table 15. Fig. 19 shows the schematic sketch of development of one day old larvae.

MIGRATION

Hilsa, like several other shads, is a migratory fish, migrating long distance from the sea to rivers for completing its life cycle. Several workers have attempted to study the migratory nature of hilsa and there were differing observations and opinions due to the complex nature of the life cycle of the fish. The fish is a fast swimmer (Southwell and Prashad, 1918) and has long been considered fluvial anadromous, which grow in sea and spawns along the lower and middle reaches of rivers (Dutt, 1966). On the

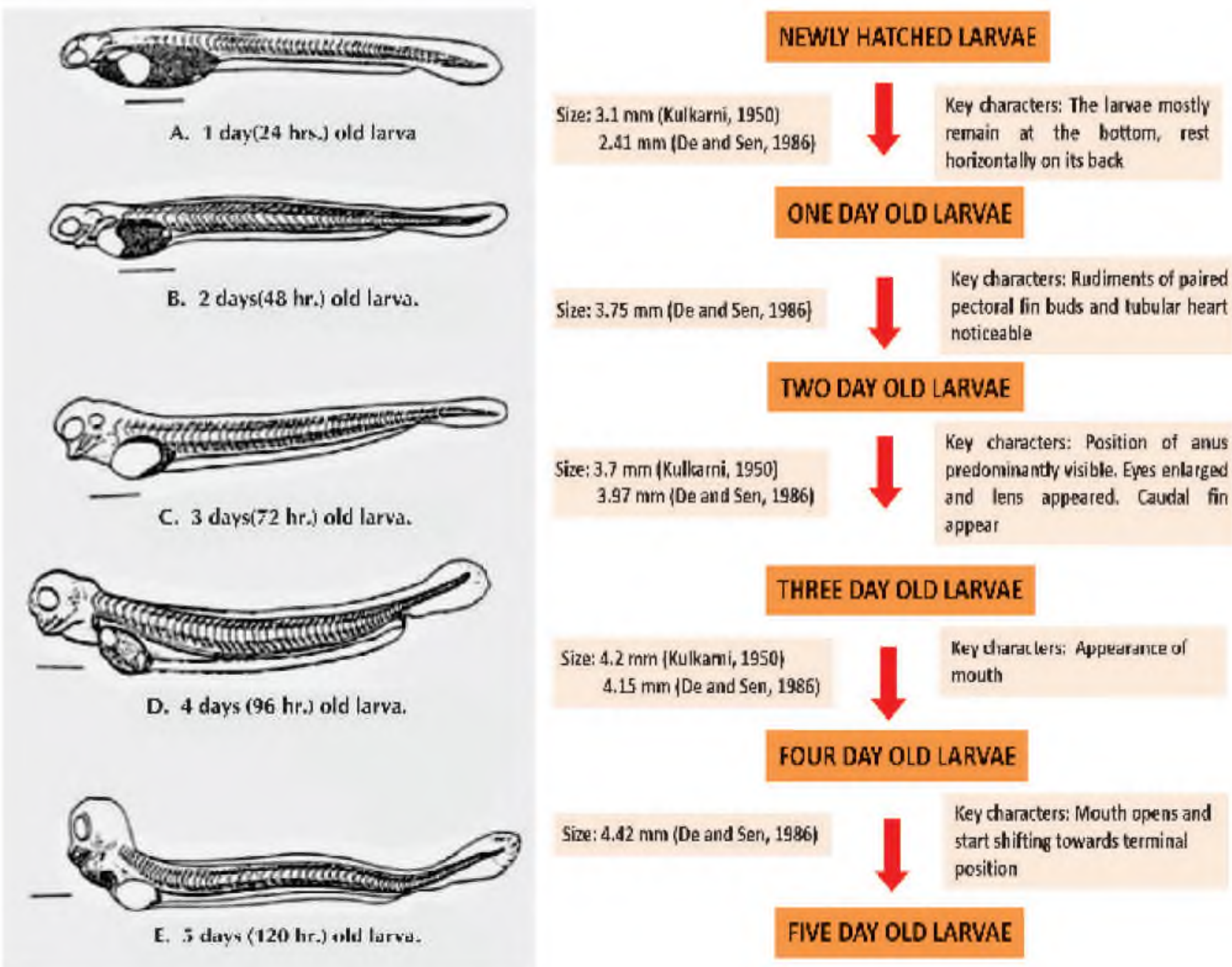


Fig. 19. Larval development from Day 1 to 5 after hatching. Source: Kulkarni (1950)

other hand, Prashad (1919) and Hora (1938) expressed doubts on its true anadromous habit stating that it does not go beyond the estuary. Since then, although various workers have observed either juveniles or adults in inshore waters (Dutt, 1966), there has been questions on the anadromous habit of the fish. However the widely accepted migratory habit of the fish is that of Pillay (1964), Dutt (1966) and Haldar et al. (2005) that hilsa ascends the rivers for spawning (Hora, 1938; Pillay, 1958b; De, 1986 and Bhaumik and Sharma, 2011) and the spawned fish as well as their progeny migrate down the river towards lower estuaries and coastal areas (Pillay, 1958b). Stocks of hilsa are anadromous, breeding much above tidal limits (Naidu, 1939). Some stocks have also been reported to remain permanently in the freshwater stretch of rivers and some spawn in tidal areas (Hora, 1938; Hora and Nair, 1940a). Pillay (1964) reported availability of maturing, mature and spent hilsa in the sea, 16 to 18 km off Veraval coast, in the northwest coast of India. Pillay (1964) presented evidence that this particular stock of the fish probably spawns in the sea. Dutt (1966), while discussing Pillay's arguments, suggested that there might be different ecotypes of the fish, which are (i) fluvial anadromous stocks that feed and grow in coastal waters and spawn in middle or lower reaches of the river above the level of tidal influence as the case for Hooghly, Godavari and Narmada rivers, (ii) fluvial form (physiologically but not geographically land-locked stocks) that inhabit the middle reaches of rivers and are potamodromous; probably that occurred at Delhi, Agra, Allahabad and Buxar areas in the rivers Yamuna and Ganga and (iii) Marine form that have been observed by Pillay (1964), off Veraval on the Saurashtra coast. The first of the above three types is the normal condition in this species and there are extensive literature pertaining to these (Jones, 1952). In the Shatt Al-Arab river, Basrah, Iraq, these fish ascend the river and reach marshy areas upstream to the north of Basrah city, but there is no record of them farther upstream. Thus, the Iraqi stock of *Tenualosa also* might fit the fluvial anadromous type of the species. The fish has two spurt of migration in Hooghly River; the peak in monsoon season and a minor one in winter season. Jones (1957) stated that the winter migration of hilsa is influenced by the rise in the temperature of water in January.

Based on observations of fishers' catches, Pillay (1958b) observed that hilsa ascend rivers only for spawning, that the spent fish as well as their progeny migrate downstream. The occurrence of two spurt of migration of hilsa in various river systems, one during the south-west monsoon and the other during late winter, has been established; the winter run is of smaller magnitude in Hooghly (Jones, 1957; Pillay, 1958b); in the Chilika lake (Jones and Sujansingani, 1951); in the Godavari (Rao, 1969) and in Bangladesh rivers (Ahsanullah, 1964; Quereshi, 1968a). The upstream migration during the main breeding season appeared to depend largely on the commencement of the southwest monsoon and consequent flooding of rivers in Bangladesh, Myanmar and India. The variations in the intensity of the monsoon during the breeding season appear to cause considerable fluctuations of the fish catches in different places (Raja, 1985). In the Hooghly estuary, the freshwater inflow attracts higher number of hilsa for their breeding migration and form a commercial fishery (De, 2001). Hilsa congregate in large numbers below dams or other obstructions (Pillay and Rosa, 1963). According to Southwell and Prashad (1918), hilsa that moves near the bottom of rivers rise to the surface when they meet obstructions such as dams or anicuts. The peak upstream migration of hilsa in most of the Indian rivers generally commensurate with southwest monsoon (July-August) and continues up to October or November. While in the Hooghly estuary, the period of migration is found to be prolonged and extended up to February. The progeny, generally after attainment of the size range from 80-110 mm, start downstream migration commencing from February and continues up to June (Southwell and Prashad, 1918). Factors like rainfall, current velocity and temperature, low salinity, turbidity, primary productivity and availability of planktonic food might be the influencing factors for commencement of migration (Bhaumik and Sharma, 2011). Peak upstream migration of hilsa in most of the rivers of the county generally start with the advent of southwest monsoon i.e., July and August and continues up to October or November (Kulkarni, 1950; Jones and Menon, 1951; Pillay and Rosa, 1963). While in the Hooghly estuary, the period of migration is found to be prolonged and extended up to winter (De, 1986; De and Saigal, 1989; De et al., 1994). Hamilton (1822) recorded the presence of hilsa near Kanpur and Agra. Day (1878) reported that hilsa ascends up to Delhi. The long range migration of the fish has also been reported from other principal river systems viz., Brahmaputra (Pillay and Rosa, 1963; Pillay et al., 1963), Mahanadi (Pillay and Rosa, 1963), Godavari (Chacko et al., 1949), Krishna (Chacko, 1954), Cauvery (Chacko, 1954), Narmada (Kulkarni, 1954) and Chilika lake (Jones and Sujansingani, 1951). Migration of the fish has been adversely affected in these rivers by the construction of dams, weirs, anicuts and barrages (Nair, 1954; Gupta and Jhingran, 1982; Panicker et al., 1982) and the fish is unable to reach its natural breeding grounds. These artificial barriers reduced the natural spawning ground as well as recruitment of the hilsa, which ultimately led to decline in catch. Overexploitation in coastal areas and at the mouth of estuaries also affected the upstream migration of the species. According to Mojumdar (1939a), hilsa moves in the sea on the surface whereas in the river they move at a depth of 14 to 18 meters, though on cool or drizzly days they may rise to within 2 meters from the surface. During upstream migration, has never been observed to form dense shoals as in the case of several other pelagic fishes. During winter months, however, they have been found to form very large shoals at the entrance of the Hooghly estuary (Howard, 1938; Hora, 1941). Pantulu (1966), as cited by Gopalakrishnan (1973), has concluded that temperature, current, velocity and volume of discharge are probably the significant directive factors to which hilsa responds in its movements from the sea to the estuary.

Table 16. Migration of tagged hilsa released in three different stretches of the Ganga river system *viz.*, Padma (P), Ganga (G) and Bhagirathi (BH) during September-November 1994.

No. of tagged hilsa released		No. of tagged hilsa recovered			Total
		Padma	Ganga	Bhagirathi	
Padma river downstream of Farakka barrage	349 (P)	30 (P)	3 (P)	5 (P)	38
Ganga river, upstream of Farakka barrage	323 (G)	5 (G)	25 (G)	38 (0)	68
Bhagirathi river	434 (BH)	Nil	Nil	42 (BH)	42
Total	**1106**				**148**

Source: De (2001)

Tagging experiments

Pillay et al. (1962) were the first to conduct tagging experiments on hilsa for studying its migratory behavior in the Hooghly-Ganga and Padma river systems. Tagging of hilsa was conducted in Ganga in the vicinity of Farakka (Table 16) during 1993 and 1994 (De and Sinha, 1987; De et al., 1994 and De, 2001). Most of the tagging was done during winter season, on mature fish, which were caught in clap nets (*Sangla jal)* and released in the Hooghly, Padma and the Ganga. The percentage of recovery were 10.81, 4.1 3, and 3.48, respectively. About 30% were recovered within 10 days after tagging and nearly 80% within a month. The maximum time interval between tagging and recovery was 770 days. While in a number of cases the fish were recovered from the same area after 2 to 4 days. Tagging experiments have shown that the fish covered long distances of 38 to 44 miles (61.2 to 70.8 km) in one day (Pillay et al., 1962). The longest distance reported was 212 miles (341.2 km) in 58 days. Pillay (1957a) confirmed that that the hilsa appearing in the Hooghly during winter and monsoon seasons belong to the same stock. Comparative account of tagging experiments and the growth of recovered hilsa by De (2001) are presented in Table 17.

Based on the examination of extensive samples of hilsa for length frequency from the inshore centers as also the sex and maturity condition of the migrants the following conclusions were drawn by Reuben et al. (1992).

- There are two well-marked migrations of marine hilsa into Hooghly river, once during post-monsoon (September/ October) and the other during the winter (January-February).
- Two size groups of 350-430 mm and 460-490 mm, former being the most dominant, participate in spring migration.

Table 17. Comparative account of tagging experiments on hilsa

Author (s)	Pillay et al. (1962)	De and Sinha (1997); De (2001)
Place of experiment	Hooghly, Padma and Ganga	Bhagirathi, Padma and Ganga
Year and season of experiment	Winter fishing season (1959), Pre-Farakka barrage period	September to November (1994), Post-Farakka barrage period
Tag used	Nylon streamer tag	Floy T-bar anchor tag
Number tagged	5875	1106
Percent recovered	7.8	13.32
Speed of migration	Variable; fish covered 61- 71 km in one day	Variable; 5 to 6 km per hour in most cases; can cover 300 km in 3days.
Longest time interval between tagging and recovery	770 days	946 days
Migratory behavior	Hilsa of the winter run had been observed to come up the estuary during the following or subsequent monsoon season and vice versa for breeding and the upstream migration starts in August and continues up to October and downstream migration takes place only in November and December.	Hilsa could negotiate Farakka barrage only during flood season when bays of the barrage were opened and water level on both up and down sides of the barrage was nearly equal. Recovery of spent fish suggests their breeding above the barrage.

- The monsoon run of hilsa comprised two groups of 310-370 mm and 420-500 mm; the latter being most dominant.
- Fish of less than 300 mm length also enter the river sporadically in very small numbers along with the larger size groups.

With reference to hilsa of the south Indian rivers, Raj (1937) stated that the fish spends the first year of its life in the lower reaches of the rivers and move to the sea in the third year, but Jones and Menon (1951) observed that this is not the case in Bengal waters. Raj (1937) also reported that shoals of hilsa visit the Palk Bay annually from November to May. The extent of migration in the rivers varies considerably. In the Irrawady, hilsa ascended to a distance of about 724 km from the sea. The range of migration in the Brahmaputra was up to Tezpur, a distance of about 306 km from the Bangladesh border. The stock of hilsa in the river Ganga was as far as Agra and Delhi, a distance of about 1287 km before the Farakka barrage (Pillay and Rosa, 1963).

PHYSIOLOGY OF MIGRATION AND REPRODUCTION

Studies on physiology of fish migration have been focused on salmonids. The parr-smolt transformation has been well characterized and these studies stand as examples of the interface of behavioural, physiological and ecological approaches to biology. The information available on the migratory adaptation of salmon in general are that of Pacific Salmon (Dittman and Quinn, 1996; Carruth, 1998; Carruth et al., 2000 and Carruth et al., 2002), The physiological mechanisms that underlie Sockeye salmon migration initiation and homing ability, particularly for adult spawning migrations, has received considerable attention (Hasler and Sholz, 1983; Quinn, 2005; Hinch et al., 2006 and Ueda et al., 2007). For example, river temperature influences the migration timing of Sockeye (Hodgson and Quinn, 2002) and Fraser river populations that migrate over short distances will generally time their migration runs in late summer and fall, to take advantage of cooler water temperatures (<18 °C) and reduced river discharge (Hinch et al., 2006). Average water temperature during egg incubation has an important influence on early development and therefore, indirectly on timing of the spawning migration. As migrants transition between the marine and freshwater environments, they reorganize their osmoregulatory and ionoregulatory systems. This transition includes changes in gill and gut and regulation of kidney activity (Wood and Shuttleworth, 1995). Consequently, routine plasma ion concentrations, plasma osmolality and gill Na^+/K^+-ATPase are generally maintained at lower levels upon freshwater entry. During upriver migration, changing levels of reproductive hormones regulate the development of secondary sexual characteristics and gonads (Leonard et al., 2001). Sockeye salmon cease feeding prior to freshwater migration initiation and rely on endogenous energy reserves to reach spawning grounds, secure a mate and spawn. For female sockeye, the majority of energy (~55 %) is catabolised for swimming activity and an additional ~23 % is diverted to ripen gonads and reproduce (Brett, 1995). Physiological sampling of fish between 700 and 250 km away from river entry showed that they are pre-prepared for the transition to freshwater well before arrival at the river mouth. In addition, reproductive hormone concentrations are also elevated indicating a preparatory period for initiation of migration. Hence age and growth are critical factors for migration.

Migration is closely associated with gonad maturation, which is regulated mainly by the brain-pituitary-gonad (BPG) axis. Activation of the BPG is likely tied to the photoperiod and takes place well before the fish starts migration. Gonad growth and maturation entail release of gonadotropin releasing hormone (GnRH) from the hypothalamus, which further stimulates release of gonadotropin from the pituitary and ultimately leads to increase in the circulating level of sex steroid testosterones viz. 11-ketotestosterone in male and estradiol in female. Stimulation of hypothalamus-pituitary-interrenal (HPI) axis in fish results in an increase in the plasma-cortisol concentration and changes in other compounds vital for homeostasis during their migration to fresh water. The studies on the role of corticosteroids in osmoregulation of fishes have been reviewed by Dharmamba (1979) and role of cortisol and cortisone in regulating sodium and chloride ions for freshwater osmoregulation through gills and kidneys of salmon has been highlighted. In anadromous salmonids, both smoltification and entry into salt water are accompanied by increases in plasma cortisol and the activity of the Na^+/K^+-ATPase pump (McCormick and Saunders, 1987; Thorpe et al., 1987). These correlative observations suggest a role for cortisol in the development of hypo-osmoregulatory functions in salmonids; however, in vitro results recently established a direct stimulatory effect of cortisol on Na^+/K^+-ATPase in Coho salmon gill tissue (McCormick and Bern, 1989). Furthermore, in a series of recent reports, gill Na^+/K^+-ATPase activity in non-anadromous rainbow trout, *Oncorhynchus mykiss* (Walbaum) (*Salmo gairdneri*), and Sea trout, *Salmo trutta*, has been shown to respond positively to injections of cortisol (Madsen, 1990a,b,c). Completion of smoltification is influenced by size (Boeuf et al., 1985) and several environmental factors including photoperiod (Solbakken et al., 1994). During seawater acclimation, salmon smolts experience hyper osmotic stress, resulting in an initial and rapid increase in plasma ion concentrations (McCormick et al., 1998) and tissue dehydration (Blackburn and Clarke, 1987). This is followed by an adjustment period, the duration of which varies with size of fish (Bjerknes et al., 1992); smolt status (McCormick et al., 1998; Sigholt and Finstad, 1990) and temperature (Sigholt and Finstad, 1990). Physiological response of salmon smolts acclimated to brackish water (28 ppt) is not different from that of smolts acclimated to full strength seawater (34 ppt) (Handeland et al., 1996). When smolts are retained in freshwater after completion of smoltification, it has been reported that their gill Na^+/K^+-ATPase (Duston et al., 1991), condition factor (Farmer et al. 1978) and lipid and water content (Farmer et al., 1978) revert back to parr levels and their salinity tolerance is lost (Duston et al., 1991). Dietary supplementation of NaCl and other inorganic salts have been shown to increase gill Na^+/K^+-ATPase and seawater tolerance in salmonids.

In Atlantic salmon (*Salmo salar*) salinity tolerance is a size-related process in which fish that have achieved a minimum size (e.g. 12 cm in winter) will become smolts the following spring (McCormick et al., 1998). Along with cortisol, prolactin was also found to play regulatory role for Na uptake by gills and kidney (Pang, 1997). Prolactin as freshwater adapting hormone has been clearly established through prolactin treatment in salmon and the increase in plasma prolactin levels during freshwater exposure. Plasma osmolality and cortisol exert direct regulatory actions on prolactin secretion. Some works have discussed lipid metabolism in terms of osmoregulation of Atlantic salmon and the role of non-esterified fatty acids (NEFAs) in plasma (Nordgarden et al., 2002). Size dependent tolerance to salinity has been indicated in Salmonids (Stephen et al., 1987) and indicated the role of gills, kidney, urinary bladder and gut of salmonids in osmoregulatory process. The Na^{+}/K^{+}-ATPase is localized in the chloride cells of the gills (Maetz and Bornancin, 1975). During salinity challenges, additional energy is required to simulate the activities of Na^{+}/K^{+}-ATPase and other transports of enzymes in the gills and other osmoregulatory organs. Hence the role of carbohydrate/ glucose/ glycogen metabolism in osmoregulation is important. The role of lipids in dietary intake is important. Minerals play an important role in osmoregulation and sexual maturation of fish. The gill Na^{+}/K^{+}-ATPase activity of Atlantic salmon decreased during upward migration indicating that the hypo-osmoregulatory ability was suppressed during sexual maturation and spawning migration (Persson et al., 1998). Peter (1982) noted that positive feedback by testosterone on pituitary GtH levels is important in triggering gonad development in anadromous fishes. Above normal levels of testosterone stimulated gonad development through production and release of GtH by pituitary. Thyroid hormones might be crucial for the increased tendency of GnRH expression and the migratory behaviour of Chum salmon. Increased salinity tolerance is brought about by changes in the major osmoregulatory organs (gill, gut and kidney) and include up regulation of ion transporters such as gill Na^{+}/K^{+}-ATPase activity. Changes in osmoregulatory physiology of smolts are regulated by growth hormone (GH), insulin-like growth factor I (IGF-I) and cortisol (Hoar, 1988). Thyroid hormones probably play an indirect role in osmoregulatory physiology and are important in controlling smolt morphology and behaviour. Temperature and photoperiod is influencing the migration of *Oncorhynchus* spp. (Clarke, 1997). Plasma cortisol and prolactin concentrations were high in seawater, suggesting a preparatory endocrine signal before freshwater entry. Generally, the mRNA expression for GR1, GR2 and MR declined during migration, most notably after fish entered freshwater. In contrast, PrlR mRNA increased throughout migration, particularly as Sockeye approached the spawning grounds. A highly significant association existed between gill PrlR mRNA and gill NKA α1a mRNA. GH1R mRNA also increased significantly, but only after sockeye had migrated beyond tidal influence in the river and then again just before the fish reached the spawning grounds. These findings suggest that cortisol and prolactin stimulate ionoregulation in the gill as Sockeye salmon adapt to freshwater (Flores et al., 2011). The majority of Pacific salmon are semelparous and failure to migrate to the spawning grounds in freshwater means an individual does not contribute genetically to future generations, resulting in no lifetime fitness (Dingle, 1980). Maturing adults that are leaving the ocean for freshwater undergo physio-biochemical transformations to maintain osmotic and ionic homeostasis (Shrimpton et al., 2005). Such ability is dependent on the regulation of water and ions by several organs, such as, gills, intestine, urinary bladder and kidney. The gills playing the primary role in the maintenance of ion balance in fish acclimatized to both freshwater and seawater (Marshall and Grosell, 2006). The need to respond to salinity change may be rapid, such as during tidal cycles or rapid movements through estuaries, or slow, such as in the seasonal or ontogenetic acquisition of salinity tolerance in anadromous fish. The former requires rapid activation of existing mechanisms, whereas the second requires differentiation of transport epithelia and synthesis of new transport proteins.

Among the osmoregulatory organs, gills are the most important and specific ionocytes. Mitochondrion-rich (MR) cells (formerly called chloride cells) are the major cells in fish gills that actively transport ions. These ionocytes secrete and absorb ions in seawater and freshwater environments, respectively, in addition to carrying out acid-base regulation and ammonia excretion functions (Evans, 2008; Marshall and Grosell, 2006). Fish iono/osmoregulatory mechanisms have long been an important topic for fish physiology itself and also for comparative studies from an evolutionary point of view. Several literature are available on the iono/osmoregulatory mechanisms of fish gills; however, many issues remain debatable, conflicting, or unsolved, due to differences in species and experimental designs, as well as limitations of methodologies. Presently, highly advanced approaches employing cell biology/ molecular physiology and model animals are available. There is substantial evidence indicating that the major transporters involved in salt secretion in the gill includes basolaterally located Na^+/K^+-ATPase (the sodium pump) and Na^+/K^+, $2Cl_2$ cotransporter (NKCC) and an apical Cl_2 channel that appears to be homologous with the cystic fibrosis transmembrane conductance regulator (CFTR). The site and mechanism involved in ion uptake in fresh water are less certain. Both chloride cells and pavement cells may be involved in sodium and chloride uptake. While we know much regarding the morphological, behavioural and physiological changes that occur during the downstream migration of juvenile salmon smolts as they prepare for entry into seawater (McCormick and Saunders, 1987), comparatively little is known regarding migration of adults from seawater to freshwater spawning grounds. Increases in gill Na^+/K^+-ATPase activity occur in fish in freshwater and are preparatory for the increased ionic concentration of sea water as juvenile salmon migrate to the marine environment (McCormick and Saunders, 1987). Infact, the elevation in enzyme activity has been proposed as predictive of the entry date into seawater (Nielsen et al., 2004). Richards et al. (2003) demonstrated differential mRNA expression of Na^+/K^+-ATPase α-subunit isoforms in response to seawater transfer and speculated that isoform switching between a freshwater-responsive Na^+/K^+-ATPase isoform (α 1a) and a seawater-responsive Na^+/K^+-ATPase isoform (α 1b) is important for ionoregulatory competence during salinity transfer. Isoform switching potentially offers a highly sensitive indicator of osmoregulatory status. The elevated gill Na^+/K^+-ATPase activity limits ionic perturbation in plasma of fish following movement into seawater. Fish transferred to seawater that are not prepared for the increased salinity showed large perturbations in plasma ions and decreased survival (Shrimpton et al., 1994) and reduced swimming performance (Brauner et al., 1992). Juvenile salmon that are prevented from migrating into the ocean survive in freshwater (Shrimpton et al., 2000); in contrast, there is evidence that maturing adult salmon cannot remain in seawater, but must move into freshwater. Hirano et al. (1978) showed that maturing Chum salmon *O. keta* did not survive transfer from freshwater into full strength seawater and the physiological changes in ionoregulatory ability that accompany maturation appeared to be irreversible. Plasma osmolality and chloride in four sockeye populations examined suggested that fish sampled in full freshwater were switched from seawater ionoregulation to chloride uptake for fish directly transferred from seawater to freshwater has been shown to take approximately 4 days (Battram and Eddy, 1990). Perturbations in plasma osmolality and chloride, although in the opposite direction, are similar in magnitude to those seen in smolting (Blackburn and Clarke, 1987); suggesting ionoregulatory changes that are preparatory for freshwater entry have already occurred in seawater. Gill Na^+/K^+-ATPase activity showed little change between freshwater samples; however, Na^+/K^+-ATPase α1a mRNA expression indicated that physiological changes continued after movement into freshwater. The decline in gill Na^+/K^+-ATPase activity as sockeye migrate to spawning areas may reflect physiological adjustments that continue to occur as the fish migrate. Previous work has shown that circulating cortisol levels increase during maturation (Donaldson and Fagerlund, 1972; Carruth et al., 2000) and the gene is possibly responsive to the higher cortisol levels.

The neuroendocrine system is the primary link between seasonal environmental changes and physiological adaptations; therefore, the hormonal control of NKA is critical for maintaining homeostasis in both freshwater and seawater (McCormick, 2001). Cortisol and prolactin increase when fish move from seawater to freshwater indicating the possibility that they have a link to seawater acclimation (McCormick, 2001). Studies focused on regulation of gene expression for vasotocin (VT), growth hormone (GH) and prolactin (PRL), to understand molecular events that underlie osmoregulation of homing salmon. In the SW to FW transfer experiments, expression of VT and PRL genes in pre-spawning Chum salmon changed within a few days in both SW and FW environments, with loss of salinity tolerance and progress in final maturation. The temporal changes in gene expression for these osmoregulatory hormones can be predictive or preparatory for the forthcoming FW migration. The profiles of migratory behavior from SW through FW suggested that homing salmon continued vertical movement between SW and FW environment in the mouth of the river for a while, followed by upstream migration to FW. As mentioned above, salinity tolerance is gradually attenuated with progress of gonadal maturation. Such vertical movements between SW and FW may help decrease the plasma Na^+ levels and maintain internal milieu favorable for the forthcoming FW migration and spawning. Preference to FW in pre-spawning chum salmon was related to circulating levels of sex steroid hormones. This finding supports that sGnRH neurons concordantly facilitate upstream migratory behavior and final gonadal maturation (Onuma et al., 2005). A line of previous evidence suggests that GnRH and sex steroid hormones modulate synthesis and release of VT and PRL in pre-spawning salmon. The neuroendocrine systems that govern salt and water homeostasis and migratory behavior from SW through FW should profoundly interact with the HPG-axis in pre-spawning salmon. Considerable information is available on the migratory physiology of American shad, *Alosa sapidissima*. This prominent anadromous fish deviates widely from the salmonid model. Adult shad spawn in fresh water in the spring and young shad develop the ability to enter into full strength seawater at the larval-juvenile transition, months prior to downstream migration (Zydlewski and McCormick, 1997). Physiological performance, together with ecological factors (such as predation and food availability) apparently stabilizes the timing of migration (Zydlewski et al., 2001).

Endocrine control of reproduction and spawning

Two molecular types of gonadotropin-releasing hormone (GnRH), salmon GnRH (sGnRH) and chicken II GnRH (cIIGnRH) exist in various brain regions (Amano et al., 1977). In particular, sGnRH in the olfactory system, the terminal nerve, and the preoptic area play important roles in salmon homing migration (Ueda and Yamauchi, 1995). Gonadotropin-releasing hormone (GnRH) plays dual role in gonad maturation and ionoregulation during homing migration, which is closely related to gonad maturation. In the salmon pituitary, axon terminals of salmon GnRH (sGnRH) neurons are distributed close to growth hormone (GH) and somatolactin (SL) cells, as well as gonadotrophes (Parhar and Iwata, 1994). GnRH agonist binding sites were observed in GH, prolactin (PRL), and SL immunoreactive cells of other teleost species (Stefano et al., 1999). Implantation of GnRH analog (GnRHa) into the dorsal muscle elevated the amounts of GH, PRL, and SL mRNAs during particular periods of the life cycle of growing and maturing salmon. In Masu salmon, GnRHa elevated the amounts of GH mRNA from winter through the early spring, while increased those of PRL mRNA in spring (Bhandari et al., 2003). GnRHa elevated the amounts of SL mRNAs in pre-spawning sockeye salmon (Taniyama et al., 2000). sGnRH thus appears to regulate synthesis and release of GH/PRL/SL family hormones. Salmon GnRH (sGnRH) in the preoptic area controls gonadotropin (GTH), luteinizing hormone (LH) and follicle-stimulating hormone (FSH) synthesis and release from the pituitary gland. And then, GTHs induce steroidogenesis in the gonads, and steroid hormones stimulate gametogenesis and final game maturation; estradiol-17b (E_2) and testosterone (T) are active in vitellogenesis, T and 11-ketotestosterone (11KT) in spermatogenesis and 17a, 20b-dihydroxy-4-pregnen-3-one (DHP) in final gameto-maturation in both sexes (Nagahama, 1999). It has been investigated hormone profiles in the BPG axis of salmon during homing migration as well as gonadal maturation (Ueda, 1999; Makino et al., 2007). sGnRH and E_2 synergistically increased the amounts of GTH II β mRNA in maturing males, while decreased those of α_2 and GTH Iβ mRNAs in pre-spawning females. Therefore, sGnRH may directly and/or indirectly regulate GH, PRL, and SL cells in combination with the pituitary–gonadal axis, i.e., sex steroid hormones. It is now well accepted that the functional roles of gonadal steroid hormones in salmonid gametogenesis are estradiol in vitellogenesis, 11 keto testosterone in spermatogenesis, and DHP in final gamete maturation (Nagahama, 1994). The shifts from estradiol to DHP in females and 11 KT to DHP during homing migration as predominant steroid in serum are also found in other salmonid species (Ueda and Yamauchi, 1995). Although the roles of testosterone in gametogenesis have not been clarified yet, high serum levels of testosterone are detected in many salmonid fishes of both sexes during spawning period (Fitzpatrick et al., 1986; Mayer et al., 1992) and testosterone was considered to be a substrate for estradiol and 11 keto testosterone biosynthesis (Kagawa et al., 1982; Ueda et al., 1984). During spawning migration of salmonids, serum testosterone levels maintained high and declined after spawning (Slater et al., 1994). The peak of plasma testosterone levels in land-locked sockeye salmon of both sexes was observed at the time when they gathered at the mouth of natal stream in Lake Chuzenji (Ikuta 1996). Changes in gonadal steroids in lacustrine sockeye salmon revealed that the shortening of homing duration coincided with the increase of serum T and 11 KT levels, and the reduction of homing percentage is associated with the decrease of serum T levels and increase in serum DHP levels. In females, the shortening of homing duration is associated with elevation of serum T and DHP levels and drop of serum estradiol levels. Moreover GnRH analog implantation is highly efficient in shorting of homing duration, especially in females. The homing behavior in lacustrine sockeye salmon is sexually different and these differences may be reflected by changes in serum steroid hormone levels, particularly of testosterone. Scanty information is available on migration changes in physiology and of steroid hormones in relation to gonad maturation and spawning in hilsa. Pramanick et al. (2013) reported bi-annual spawning during April to May and August to September in hilsa based on seasonal changes in gonado-somatic index (GSI). Coinciding with GSI values, sex steroids, such as, estradiol and testosterone declined from October reaching lowest value in January and thereafter, rapidly increased in March when ovary contained mostly vitellogenic follicles and remained high till April, whereas 17α20β- dihydroxy (DHP) was detected in March and reached maximum at April during oocyte maturation. All steroid levels attenuated after spawning and again showed highest levels during next spawning season (Pramanick et al., 2013). Chakrabarti and Ghosh (2016) studied changes in the histological architecture of thyroid and testicular tissues of hilsa and their work showed that secretory activity of thyroid follicles fluctuated in harmony with the testicular cells during growth, maturation and spawning phases indicating the correlated cytological changes in the two tissues. Further detailed study including large number of different size of adult hilsa is essential to understand annual reproductive cycle and progress of gametogenesis in association with changes in plasma sex steroid levels in wild hilsa. Similar study in captive rearing hilsa will throw light on the intervention feasibility for captive maturation and spawning of the fish.

CATCH AND TIME SERIES CHANGES IN CATCH

Clupeid fishes in general and hilsa in particular are characterized by substantial year-to-year, season-to-season and area-to-area fluctuations in availability; such fluctuations may be caused by variable success in fish recruitment which, in turn, is regulated in complex and non-predictable ways by physical, biological and fishing related ways (Cole and McGlade, 1998). Of this monitoring and managing of fishing pressure is, to an extent possible, hence continuous monitoring of fishing methods, catch, effort and other related fisheries parameters are important in managing natural stock of fishes.

Fishing methods

The riverine/ estuarine stocks are exploited by a variety of gear, the most common are gillnet, clap net, seine net, barrier net and fixed bag net. However, the maximum contribution comes from gill/ drift net. Mechanized fishing with gillnets account for the bulk of the landing from the sea, both in India and Bangladesh. The fishermen's choice of nets for operation in different areas and different seasons depends on the velocity of current, nature of catch and to a large extend on financial condition. Hornell (1924, 1950), Naidu (1939), Ahmed (1954) and Jones (1959a and b) have described hilsa fishing gear and its operation in the Indo-Bangladesh regions. The information contained in these reports have been summarized and tabulated by

Pillay and Rosa (1963). The traditional boats, which are plank-built, un-decked or partly decked, are the most common in the rivers. However, mechanized multiday fishing boats are employed for hilsa fishing in marine waters. A description of the types of fishing boats was given by Pillay and Rosa (1963). In Hooghly-Bhagirathi river system, the gear used for exploitation of hilsa vary in types and sizes. Information on the different fishing gear used in rivers, estuaries and coastal waters for exploitation of hilsa is available from Swarup (1958), Jones (1959a), Saxena (1964), Saxena and Chandra (1968), De (1980) and Mitra *et al.* (1987). The most important gear for exploitation of hilsa are gill nets, boat seines and clap or purse nets. Gill nets and boat seines are commonly used in coastal areas, estuaries as well as middle and lower stretches of the Ganga, whereas Clap nets *(Sangla jal)* are mostly operated in upper stretches of the estuary. Moreover, *Bandal* fishing (trap fishing) was common in the Ganga during peak fishing season. There are two types of gill nets *viz.,* drift gill net *(Chandi jal)* and set gill net *(Nangar jal)*. *Chandi jal* is one of the important gear for exploitation of hilsa. It consists of several pieces of netting, each piece having a length of 8-20 m and height of 5 to 13 m depending on sizes and

Trawlers at marine sector

Boats used along brakish water/ nearshore area

Wooden boats in freshwater stretch

Boats made of tin sheets (at Farakka)

Fishing crafts popularly used for hilsa fishing area of operation. The mesh variation in gill net and selectivity factors are highly variable. Mesh size generally varies from 60 mm to 100 mm. While, Reuben et al. (1992) reported smaller sized *Chandi jal* (drift gill net) with a mesh opening of 50-80 mm is also used in the coastal waters of Bay of Bengal. The gill nets are made of nylon monofilament. In Hooghly estuarine system alone, more than 0.2 million drift gill nets are in operation (Mitra et al., 1987; De, 1991). Presently more than 5957 small mechanized and 1533 non-mechanized boats (DoF WB, 20l2), mostly equipped with drift gill net containing 100 to 500 pieces (total length comes to 500 to 1000 km) are actively engaged in the coastal areas of West Bengal. Fishing activities are mainly confined to marine zone of the estuary within 30 to 40 km off shore and the inshore areas up to 50 m depth. In coastal areas, the peak fishing season lies between July and November.

Generally the fishers start their journey in the morning and reach the fishing spot after three hours navigation. If their fishing operation is for a day they immediately start shooting their nets in the water and haul it in the afternoon. In case of fishing operation for two to three days, they carry ice and prefer to fix nets in the evening when they get more catch. Exploitation of hilsa in fresh and estuarine waters extends almost throughout the year, which peaks during post monsoon to spring (July-August to February-March) when hilsa migrate upstream for spawning.

Remesan et al. (2009) have dwelt upon the non-selective gear and sustainability issues relevant to Hooghly-Matlah estuary and inferred that gear *viz. Behunti Jal*, a stationary bag net, with wide mouth of 27 m and very small cod end mesh size (0.2 mm), *Char-pata Jal*, a screen barrier net, having very small mesh operated for harvesting juveniles and *Sitki Jal,* a skimming net, made up of polyethylene netting of mesh size of about 0.2 mm for collecting fry and fingerlings, are non-selective and highly detrimental for sustaining the fisheries. Table 18 depicts the number of licensed boats operated in the inland and coastal sector, where hilsa constitute the main catch along West Bengal coastline. The size of the mechanized boats vary between 31 to 36 feet length overall (LOA) fitted with 15 HP engines and 51 to 58 feet length overall (LOA) fitted with 105 HP engines.

Table 18. Licensed boats in operation for fishing in inland and coastal waters of Hooghly-Bhagirathi system

Year	Mechanized			Non-mechanized		
	Purba Medinipur	South 24 Parganas	West Bengal	Purba Medinipur	South 24 Parganas	West Bengal
2002-2003	174	1015	1189	2	240	242
2003-2004	395	1908	2303	9	295	304
2004-2005	843	1761	2604	72	609	681
2005-2006	754	1279	2033	146	341	487
2006-2007	830	1490	2320	43	222	265
2007-2008	989	2241	3230	Not available	Not available	Not available
2008-2009	1221	1759	2980	670	552	1222
2009-2010	1150	2382	3532	100	1136	1236
2010-2011	1656	3459	5115	131	913	1044
2011-2012	1703	4254	5957	67	1466	1533

Source: Directorate of Fisheries, West Bengal


Clap net


Lift net


Bag net


Gill net


Seine net


Gill net in marine sector

Different types of nets used for hilsa fishing

In estuarine to freshwater zones only small non mechanized boats are in use.

Catch trends

The status of knowledge on catch of hilsa varies greatly between hilsa fishing countries. The fish accounted for 48% of the total fish production of Kuwait during 1965-1974, which gradually declined to 28% and 12% respectively during 1990-2002 and 2003-2007 (Al-Dubakel, 2011). Over fishing, pollution and lack of regulations to protect the marine stock are attributed to this decline. Catch rate and fishing mortality are more than maximum sustainable yield of hilsa in Iran waters (Hashemi et al., 2010). Bangladesh has benefitted greatly from a number of hilsa management measures as national responsibility; evident by improved catches (Mome and Arnason, 2007). Bangladesh shares maximum, in overall hilsa production, among the Bay of Bengal countries (Mome and Arnason, 2007). Total catch of hilsa in Bangladesh ranged between 194981 and 280328 tons with an average of 217681 per year from 1987 to 2007 and the total production increased approximately 48% during this period (Mome and Arnason, 2007). Hilsa catches in Bangladesh were 298921 t in 2008-2009 (95970 t from inland waters and 202951 t from in marine waters) and accounted for 39% of total marine catches, 4% of inland catches and 11% of total fish production (Anon, 2012). Also the hilsa catch in 2011 in Bangladesh was 313753 t (BBS, 2012). Meghna-Padma and Brahmaputra are the major sources of riverine catch. Myanmar also exploits the Bay of Bengal hilsa at 4000-5000 t/year (BOBLME, 2010), which is much low as compared to Bangladesh and India and very less information is readily available from Myanmar on fishing gear, vessels employed and overall catch trends. Hilsa is a highly fecund species and this may protect it to some extent from overfishing, however, pollution, degradation/ loss of habitat, impaired flows in rivers, obstruction to migration for breeding are affecting the distribution and probably the productivity of the stock.

In India, hilsa fishery exists mostly in the rivers draining in to the Bay of Bengal, mainly the rivers Hooghly-Bhagirathi, Godavari and Mahanadi and the coastal lake Chilika along the west coast and rivers Narmada and Tapti and their estuarine areas along Arabian Sea. However, about 90% of the hilsa catch in the country comes from the Hooghly-Bhagirathi river system. The Indian status reports on hilsa by Department of Fisheries, West Bengal indicated increasing fishing efforts and declining catch. Limited assessment of the optimal production in India indicated that their populations are probably overfished. Hydrological modifications in almost all the westward and eastward flowing major rivers have adversely impacted the species and the overall catch is declining (Bhaumik and Sharma, 2011). Conservation efforts are being implemented, mostly in West Bengal and Gujarat part of the fishing area. Reliable statistics of hilsa catch for the river Ganga and Hooghly estuary and some fragmentary year wise landing data for the rivers Godavari, Mahanadi, Narmada, Brahmaputra and Chilika Lake are available (De, 2001).

Ganga river system: Hilsa used to be abundant in the middle and lower stretches of the Ganga river and formed a lucrative fishery until 1972. The average annual landings of hilsa at Allahabad varied from 6.9 to 283.5 t during 1955 to 1972 with an average of 48.4 t. According to Swarup (1958), hilsa fishery thrived throughout the year in the Ganga and its tributaries near Allahabad with peak during October and November. At Allahabad centre, the average annual catch during 1955 to 1957 was 183 t from the river Ganga (Ghosh, 1965). At Buxar, the average annual hilsa landing was recorded as 140.63 t during 1952 to 1954 (Jhingran, 1957). Later on, the hilsa catch at this centre fluctuated between 7.3 t and 113.4 t with an average of 33.0 t during 1963-72. After commissioning of Farakka barrage in 1975, the average annual hilsa landing at Allahabad varied from 0.13 to 1.75 t with an average of 0.96 t during 1975 to 1994. Similar setback of hilsa catch was also observed at Buxar and Bhagalpur during post barrage period. Moreover, the fish vanished from the upstream of Ganga above Farakka barrage. The impact of Farakka barrage on hilsa fisheries in river Hooghly has been examined and discussed thoroughly by Mukherjee and Suresh (2007). Before the construction of Farakka barrage across Ganga, the rivers viz., Ganga, Yamuna, Hooghly and Brahmaputra together contributed 70% of the total hilsa production of the country (De, 2014). Vass et al. (2010) has given a detailed account of the decline of hilsa fisheries in Ganga. The shift in landing of hilsa at various landing centers before and after the construction of Farakka barrage is shown in Fig. 20. After the barrage, hilsa fishery collapsed in the stretch above the barrage, apparently due to obstruction of migration by the barrage.

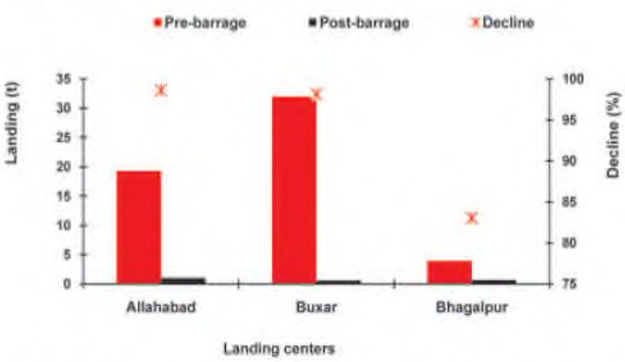


Fig. 20. Mean landing of hilsa at Allahabad, Buxar and Bhagalpur during pre and post Farakka barrage period Source: Vass et al. (2010)

Farakka barrage

Hilsa is the major component of fishery in the Hooghly estuary, accounting for 15-20% of the total fish landing. The annual hilsa catch from the Hooghly estuary are highly fluctuating over the years. During pre-Farakka period (1957-74), the annual landings of the species varied between 114 and 6573 t with an average of 1427.6 t, which increased during post-barrage period. The average annual harvest of hilsa ranged from 2471 t to 6370 t during 1975-76 to 1990-91 and 1991-92 to 1998-99, respectively (CIFRI, 1976-2000). Hilsa landing in the Bhagirathi-Hooghly river system during 2000-01 to 2010-11 varied between 12733 and 77912 t. The observations on production trends for five decades indicate that every 10 to 12 years, there is spurt in the hilsa production. The total hilsa landing from Hooghly river system during 2002-03 was 62,600 t, which declined to 14005 t during 2009-10. However, there has been high catch during 2010-11 (59795 t). The marine catch has declined from 32000 t during 2000-01 to 11744 t during 2008-09; the inland catch too declined from 34200 t

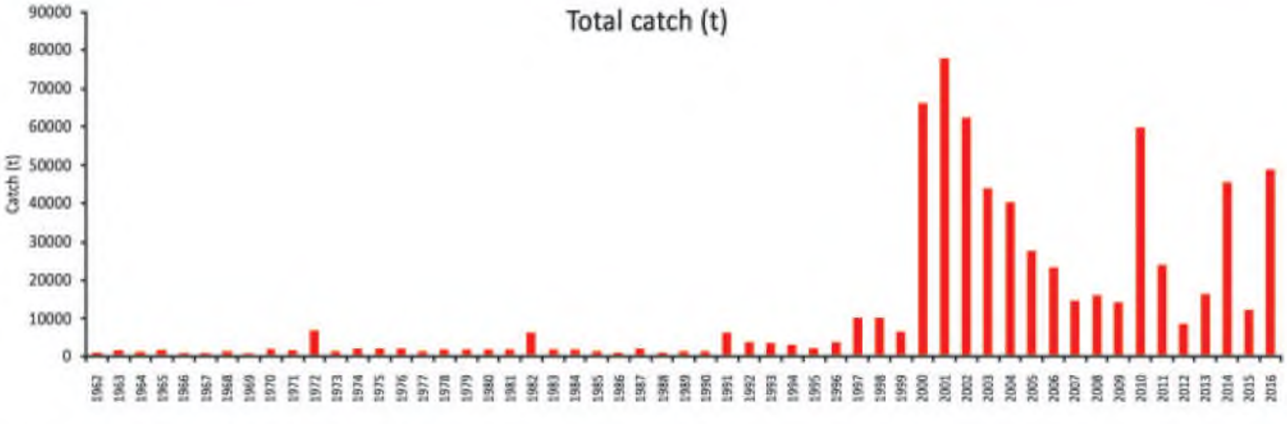


Fig. 21. Hilsa landing from inland stretches of Hooghly river system. Source: ICAR-CIFRI; Department of Fisheries, West Bengal, NASF Project on hilsa

during 2000-01 to 4256 t during 2008-09. However, there has been increase in the marine catch, which is attributed to increased effort by mechanized trawlers and gill-netters. The time series catch trend of hilsa since 1962 to the recent available estimates from inland sector of Hooghly is shown in Fig. 21. Fig. 22 shows the catch trend of hilsa from inland and marine (off Hooghly estuary) since the year 2000, which indicate progressive decline in catch from Inland areas of the river. Based on the investigation conducted by CIFRI, it was stated that commercial hilsa fishery constitute fishes of lengths varying in the range of 300 mm to 480 mm during June-August, and 300 mm to 400 mm during January to March (Bhaumik and Sharma, 2011).

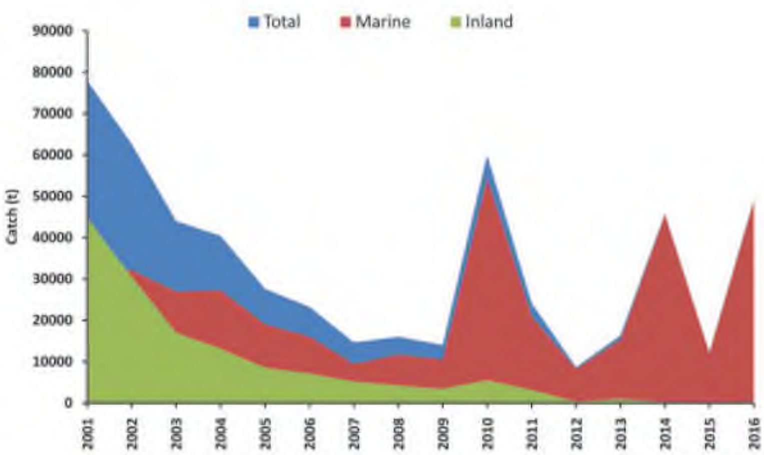


Fig. 22. Catch trend of hilsa from inland and marine (off Hooghly estuary) areas since the year 2000-01. Source: ICAR-CIFRI, Department of Fisheries, West Bengal; NASF Project on hilsa

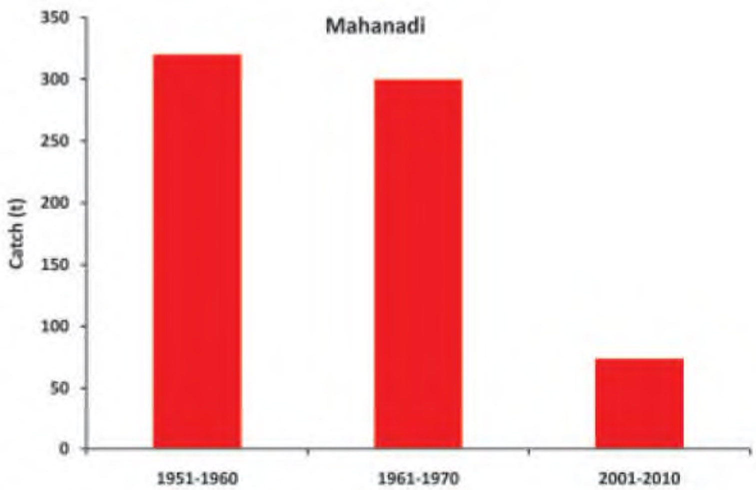


Fig. 23. Catch of hilsa from Mahanadi estuary. Source: ICAR-CIFRI

Fry and fingerlings of the species are available in varying quantities in the extended freshwater stretch of the estuary during November to June and even up to early July with certain degree of peak availability during November to January (De, 1986). Indiscriminate exploitation of young

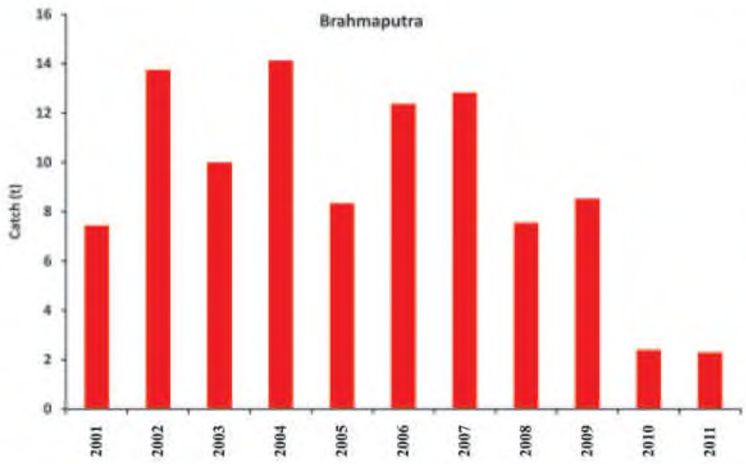


Fig. 24. Hilsa catch from Brahmaputra along Guwahati landing centers. Source: ICAR-CIFRI

Fig. 25. Declining catch of hilsa in Narmada river system. Source: ICAR-CIFRI; Directorate of Fisheries, Gujarat

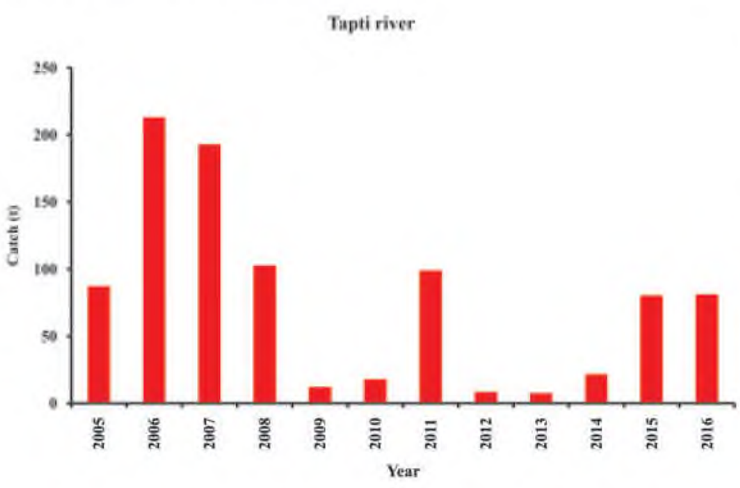


Fig. 26. Declining catch of hilsa in Tapti river system. Source: ICAR-CIFRI; Directorate of Fisheries, Gujarat

hilsa through small meshed nets (bag net and seine net) was estimated at 31.0 to 63 t and 44 to 151 t (Anon, 2004) during 1991-98 and 1998-2003 respectively.

***Mahanadi estuary*:** The average annual harvest of hilsa was 310 t from Mahanadi during 1951- to 1960; 292.7 t during 1961 to 1970 (Jhingran and Natarajan, 1969), which declined gradually 112 t during 2001-2010 (Fig. 23). Barrages and obstruction in freshwater discharge to the estuary has been attributed along with increased fishing efforts for the decline.

***River Brahmaputra*:** Hilsa production from the river system in the Indian part has been 1000 t during the 1960s and 70s; which has now declined to 2.3 t in 2011. The catch recorded during 2001 to 2011 has been highly fluctuating and is given in the following figure, which indicates a progressive decline (Fig. 24).

***River Narmada*:** The hilsa fishery in Narmada has undergone considerable decline mainly due to alternation in the hydrological regime of the river after the construction of Sardar Sarovar dam as given in Fig. 25. The catch of the fish recorded steady and progressive decline over the years and is at record low during 2015.

River Tapti: There has been a good fishery of hilsa along the estuary and freshwater stretch of river Tapti. The catch record available shows a fluctuation between 7.5 to 213 t during 2005 to 2016 with wide annual fluctuations as shown in Fig 26.

***Vallabh Sagar (Ukai) reservoir*:** It has been reported that hilsa has been completely adapted to freshwater environment of Ukai reservoir and has established self recruiting population. Table size hilsa, mostly ≤ 500 g are harvested. The annual fish catch data revealed that the contribution of *T. ilisha* in the catch varied from 1 to 52 t (0.06 to 1.76%) during 1989-90 to 1996-97. This further increased to 119 t (2.28%) during 1998-99 and further to 934 t during 2001-2002. The catch dropped steeply thereafter and during 2007-08, 2008-09, 2010-11 the catch gradually increased as 7.35 t, 65.9 t and 93.3 t respectively. The catch of juveniles also increased during this period (6.48 t, 4.6 t, 7.9 t and 22.1 t, respectively). The catch trend from the reservoir is shown in Fig. 27.

***River Godavari*:** Godavari showed a drastic decline in catch of hilsa. During 1941-1950s it was 8250 t, which declined to 5350 t and 26.99 t during 1951-1960s and 1961-1970s respectively. Recently the catch has been recorded at 14.5 t. The catch trend is shown in Fig. 28.

***Chilika lagoon*:** During 1970-1980 the average catch from Chilika lagoon was 129.2 t, during the 1981-1990 it was 252.8 t. The catch declined to 11.5 t during 2007-08 and to 4.08 t during 2009-10. The annual catch trend is shown in Fig. 29.

Hilsa fishery has been fluctuating heavily from year to year in most of the principal drainage systems of the country. Presently, besides lower

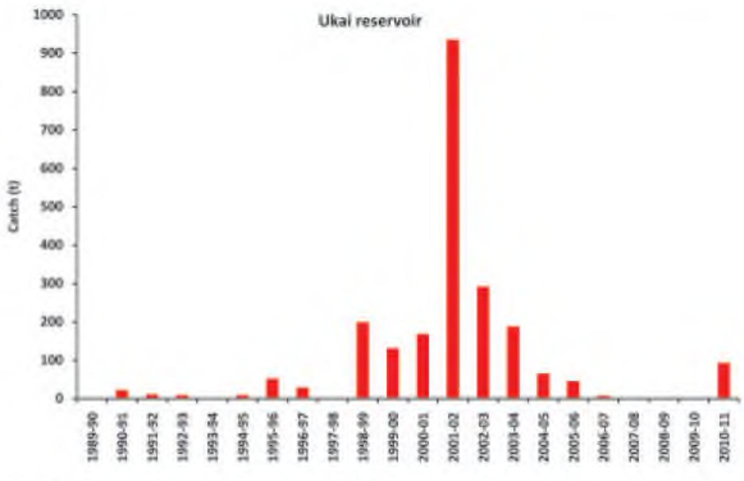


Fig. 27. Contribution of hilsa in Ukai reservoir. Source: Directorate of Fisheries, Gujarat

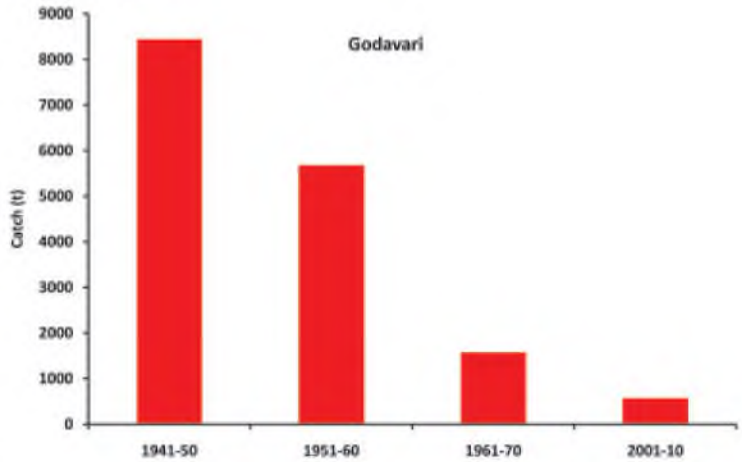


Fig. 28. Landing of hilsa from Godavari estuary. Source: ICAR-CIFRI

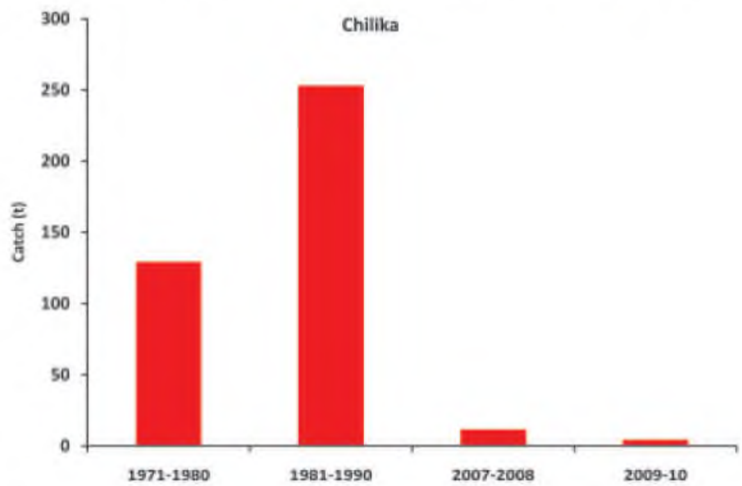


Fig. 29. Hilsa landing from Chilika lagoon. Source: ICAR-CIFRI and Chilika Development Authority

Catch from freshwater stretch

Catch by marine gill netters

Marine hilsa catch being unloaded

Hilsa catch from different sectors

marine zone of Hooghly and Narmada estuary, the abundance of hilsa has drastically dwindled in all river systems. The factors responsible for the collapse of hilsa fishery in most of the river systems are attributed to (i) construction of barrage, weirs, anicuts, etc. across the rivers, hindering spawning migration (ii) gradual loss of natural spawning ground in the upstream of rivers, (iii) high rate of exploitation at different levels of juvenile to adult stage (iv) adverse environment due to industrial waste discharge, (v) river course modifications. Hilsa landings from the marine sector has been 8287 t during 1977-80 and 30434 t during 1992-94. Similar trend has also been noticed in West Bengal coast, where the average annual yield has increased from 398 t during 1977-80 to 24729 t during 2011-12. The total annual yield from both inland and marine sectors of the country was recorded as *64235t* and 57842 t during 1991 and 1992 respectively (MFIS, 1978; 1981; 1982-83; 1989 and 1995; Govt. of India, 1996) thus contributing 1.37% of the total fish production of the country.

Catch per unit effort

In fisheries, the catch per unit effort (CPUE) is an indirect measure of the abundance of a target species and also of fishing pressure, thus used in fisheries management. However reliable CPUE data is not available for hilsa, specifically from the inland waters. Although disjointed and old, catch and effort data are available for Godavari

Rampant capture of juvenile hilsa

(Pillay and Rao, 1963; Rajyalakshmi, 1973). Amin et al. (2008) estimated CPUE and exploitation rates of hilsa in Bangladesh waters with a mean CPUE of 45.7 kg/boat/day during the peak fishing (September-October) in the Ramgoti area of Meghna river. Immature hilsa was caught by *chandi / current jal* (monofilament net, mesh size 6-8 cm) with a mean CPUE of 33.5 kg/boat/day.

The total catch of hilsa in Bangladesh was estimated to vary between 146082 and 229714 t from 1984 to 2002, with juveniles contributing 19258 t in 2000 with average weight of 10 g (Mome and Arnason, 2007). If 10-15% of these were allowed to grow, an additional 150000-250000 t of adult hilsa could be harvested each year. However from Indian side, we do not have consistent estimates of CPUE or fishing effort, barring intermittent information available in records of ICAR-CIFRI.

POPULATION DYNAMICS AND STOCK ASSESSMENT

Population dynamics involves assessment of the quantitative change in a population (a group of individuals belonging to the same species) as a result of various processes (growth, natural mortality, fishing mortality, sexual differentiation, migration, etc.). It can be used to describe the functioning of populations and their exploitation and to devise changes that would make it possible to manage them better. Population dynamics models make it possible to estimate the current status of a population (stock assessment). Depending on the status of the population, management measures may be introduced in order to bring sustainability. In India, only few authors studied the population dynamics of hilsa. Employing the length frequency method, Sarkar (1957) studied the size composition in catches from the lower Sunderbans and observed that the commercial fishery is supported by the 300-380 mm size group. Reuben et al. (1992) studies the stock structure of marine hilsa off West Bengal cost and estimated the L_∞ at 59.6 cm; K at 0.47/year; MSY at 4169 t. The most recent work in Indian waters was by Dutta et al. (2012a), who investigated population dynamics of *T. ilisha* in West Bengal coast of Northern Bay of Bengal. Their study was based at the major marine fish landing centers of West Bengal viz. Kakdwip, Namkhana and Frasergunj during June 2010 to March 2011. They estimated asymptotic length (L_∞) as 477.75 mm, growth constant (K) as 1.900/year, total mortality coefficient (Z) as 1.98/year, fishing mortality coefficient (F) as 0.73/year, and natural mortality coefficient (M) as 1.25/year. Despite some early works and the recent study by Dutta et al. (2012a), characteristics of the exploited population of hilsa is not well known from the Indian region in order to suggest exploitation strategies. Though the study on population dynamics of *T. ilisha* was initiated in Indian waters, more focused and elaborate studies were carried out in Bangladesh (Miah et al., 1997; Rahman et al., 1998; Rahman et al., 2000; Amin et al., 2000; Amin et al., 2004; Haldar and Amin, 2005; Amin et al., 2008; Rahman and Cowx, 2008). Miah et al. (1997) estimated growth and mortality parameters of *T. ilisha* populations of river Meghna. The growth parameters estimated were asymptotic length, L_∞ (57 cm), growth coefficient, K (0.66/year) and the initial condition parameter, t_o (0.50/year). The smallest length at first capture was 3.65 cm and length of larvae at the day of birth was 1.03 mm. Minimum age of hilsa entering the fishery (T_r) and the first capture age (T_c) were 0.58 and 0.60 year, respectively. The mortality parameters estimated were the total mortality Z (2.03/ year), natural mortality, M (0.89/ year) and fishing mortality, F (1.14/ year). The exploitation rate (E) of hilsa was 0.56, indicating beginning of overexploitation. Amin et al. (2000) studied the population dynamics and stock structure of *T. ilisha* in Bangladesh, using the length-frequency based FiSAT software. The growth parameters estimated included L_∞ = 60.00 cm and K = 0.82/ year. The annual mortality rates M, F and Z computed were 1.28, 2.49 and 3.77, respectively. The rate of exploitation (E) was estimated at 0.66 and that of the E_{max} was 0.59, indicating over fishing during that period. The relative yield-per-recruit (Y/R) and relative biomass-per-recruit (B/R) were determined as a function of Lc/L_∞ and M/K, were 0.38 and 2.13, respectively. The study revealed that the fishes are harvested at a higher level than the optimum fishing mortality and recommended reduction of fishing pressure to 1.88/ year from the observed level of mortality (2.49/ year) to the MSY of 162396 t. Amin et al. (2004) assessed the stock of *T. ilisha* in Bangladesh waters for three years from 1997 to 1999. The results indicated that the stock of the fish is heavily exploited and suggested that any increase from the existing effort would most likely result in a reduction in the yield-per-recruit and thereby hamper the MSY. They suggested immediate fishing regulation on the stock, which could be done by gradually increasing the mesh size of the gears or by restricting fishing for certain seasons or declaring fish sanctuaries in certain areas,

Table 19. Population and stock parameters estimated for hilsa from the Bay of Bengal

Parameters	West Bengal (Marine) (1984-88)	Mandapam (India) (1973)	Bangladesh (1985)	Bangladesh (1999)	Bangladesh (2002)	Meghna river (2005)
L_∞ (cm)	59.50	51.1	56.80	60.00	61.5	52.00
K/year	0.47	0.49	1.15	0.82	0.83	0.70
Z/year	1.71		3.10	3.77	3.29	2.61
M/year	0.70		1.23	1.28	1.28	1.22
F/year	0.94		1.87	2.49	2.01	1.39
E	0.58		0.66	0.66	0.61	0.53
E max	0.59		0.62	0.59	0.69	0.50
Lc			38.9			
Lr (cm)	16					
Lm (cm)	37					
tm (year)	1.98					
Annual catch (t)	1973			214519		
Biomass (t)	4707			335185		
MSY (t)	4169			162396		

Source: Reuben, et al. (1992), Banerji and Krishnan (1973), Nurul et al. (2002), Rahman et al. (2000), Amin et al. (2001), Haldar and Amin (2005)

especially in spawning areas. Some of the population and stock parameters estimated for hilsa from the Bay of Bengal region are shown in Table 19.

The stock assessment of *T. ilisha,* throughout its distribution range, indicated various level of overexploitation of the species. Mohamed et al. (2001) assessed the stock in Iraqi marine waters. Mohamed et al. (2001), in northwest Arabian Gulf, estimated growth and mortality parameters as L_∞ = 60.47 cm, K=0.32, Z=1.28, M=0.62, and F=0.66 with exploitation rate of 0.52, which was not exceeding the exploitation rate at maximum yield per recruitment (0.63). Some such studies have also been carried out in Iranian waters (Hashemi et al., 2010; Roomiani and Jamili, 2011). Hashemi et al. (2010) assessed the stock of *T. ilisha* in Iranian waters based on sampling from two landing centres (Hendijan and Abadan) and estimated the L_∞ and K as 43.32 cm and 0.78/ year, respectively. They obtained an exploitation rate (E) of 0.7 for *T. ilisha*, which showed overfishing. Roomiani and Jamili (2011) using the length-frequency based analysis in FiSAT evaluated the growth parameters (L_∞ = 42.74 cm, K= 0.77), mortality rates (Z= 2.55/ year, M=0.75/ year and F= 1.8/ year), exploitation rate (E=1.8/ year) and Maximum Sustainable Yield (MSY). Their study also showed that *T. ilisha* is in over fishing pressure. Panhwar and Liu (2013) studied the population dynamics of hilsa in Sindh, Pakistan.When comparing the asymptotic length values calculated by Bangladesh, India, Pakistan, Iraq and Iran researchers, the species is found larger in size in Bangladesh and Iraq waters; smaller in India and Iran and even smaller in Pakistan. The K value of 1.9/ year by Dutta et al. (2012a) and 1.5/year by Panhwar and Liu (2013) were exceptionally high and K value of 0.32 in Iraq waters is low, whereas the K values in Bangladesh and Iran waters are comparable. Growth and mortality

Table 20. Growth parameters of the hilsa in different water bodies

Area	ϕ'	L_∞ (cm)	K/year	Author (s)
India (Mandapam)	3.11	51.1	0.49	Banerji and Krishnan (1973)
India (W. B. Marine)	3.15	59.5	0.47	Reuben et al. (1992)
India (Hooghly) (M)	3.11	44.7	0.65	
(F)	3.34	46.1	1.03	Pillay (1958b)
India (West Bengal coast)	3.64	47.78	1.9	Dutta et al. (2012a)
Bangladesh (Chittagang)	3.41	55.74	0.84	Amin et al. (2001)
Bangladesh (Chittagang)	3.47	60.0	0.82	Amin et al. (2002)
Bangladesh (M)	3.47	60.0	0.82	
(F)	3.34	66.0	0.67	Amin et al. (2004)
Bangladesh	3.49	61.5	0.83	Rahman et al. (2000)
Bangladesh	3.41	55.7	0.84	Amin et al. (2002)
Bangladesh	3.33	57.0	0.66	Miah et al. (1997)
Bangladesh	3.14 (M)	51.5	0.53	
	3.34 (F)	60.0	0.51	Haldar and Amin (2005)
Iran	3.19	65.5	0.43	Parsamanesh et al. (2003)
Iran	3.14	42.7	0.77	Roomiani and Jamili (2010)
Iran	3.16	43.32	0.78	Hashemi et al. (2010)
Iran	0.2	61.2	2.89	Marammazi (1995)
Kuwait	3	52.5	0.36	Al-Baz and Grove (1995)
Iraq (Arabian Gulf)	-	60.47	0.32	Mohamed et al. (2001)
Pakistan (Indus river)	-	31.5	1.5	Panhwar and Liu (2013)

parameters of hilsa in different water bodies using length-based stock assessment method with some confirmation with otolith reading are available from different authors. The estimated growth parameters of hilsa from different parts of the world is shown in Table 20, while the mortality parameters and exploitation rates of hilsa from various ecosystems are listed in Table 21.

STOCK DELINEATION

The possibility of existence of different races of hilsa was conceived at a very early stage of investigations. The concept of presence of more than one race of hilsa has evoked great interest among researchers. Day (1873) observed two races, which ascend the rivers. Naidu (1939) explained variations in the number of lateral blotches and the absence of them in some and has raised question whether these indicate distinct races or species, or whether the feature is only a variation of coloration in the same species. Jenkins (1938) doubted whether there are two or more races or varieties of hilsa with different spawning grounds and habits. According to Mojumdar (1939a), the Padma hilsa is thicker in structure and of a bright silvery in colour, while the Meghna hilsa is thinner, slightly darker and elongated. He also suggested that turbidity and the degree of salinity are factors separating the stocks. He recognized three types of hilsa: (i) those of the seas, (ii) those from the muddy

Table 21. Mortality parameters and exploitation rate of hilsa in different water bodies

Area	Fishing mortality coefficient (F)	Natural mortality coefficient (M)	Total mortality coefficient (Z)	Exploitation rate (E)	Author (s)
India					
(West Bengal coast)	0.73	1.25	1.98	0.37	Dutta et al. (2012a)
Bangladesh (Chittagong)	3.47	60.0	0.82	-	Amin et al. (2001)
Bangladesh (Chittagong)	1.28	2.49	3.77	-	Amin et al. (2002)
Bangladesh (M)	1.25	2.18	3.43	-	Amin et al. (2004)
(F)	1.28	2.49	3.77		
Bangladesh	2.01	1.28	3.29	0.61	Rahman et al. (2000)
Bangladesh	1.14	0.89	2.03	0.56	Miah et al. (1997)
Bangladesh (M)	0.92	1.95	2.87	-	Haldar and Amin (2005)
(F)	1.01	2.07	3.08		
Iran	0.77	6.13	6.9	-	Parsamanesh et al. (2003)
Iran	0.75	1.8	2.55	-	Mohammadi et al. (2005)
Iran	1.29	3.24	4.53	-	Hashemi et al. (2010)
Kuwait	0.8	0.50	1.30	0.62	Al-Baz and Grove (1995)
Iraq (Arabian Gulf)	0.66	0.62	1.28	0.52	Mohamed et al. (2001)
Pakistan (Indus river)	0.673	2.21	2.89	-	Panhwar and Liu (2013)

freshwater of rivers Padma or Hooghly and (iii) those from the clear freshwater of Meghna. J.T.J. (1940) wondered whether the fish which spawns in the Sundarbans and those which spawn upstream Ganga represented distinct races, and if so, whether they could be distinguished. However, Hora and Nair (1940a) found no evidence in support of the possibility of two or more races from Hooghly and Ganga at Allahabad. Hora (1940) suggested that the hilsa of the Hooghly and East Bengal (Bangladesh) might represent separate stocks. Hora and Nair (1940a) found no evidence in support of the possibility of two or more races as far as the stocks of the Hooghly and those obtained from the Ganga at Allahabad were concerned. In the subsequent years (Pillay, 1952, 1954, 1957b; Pillay et al., 1963; Ghosh et al., 1968; Rao, 1969; Ramakrishnaiah, 1972; Quddus, 1982) discussed the matter of distinct stocks or not. Pillay (1952 and 1954) used biometrics and compared the data relating to body size and length of head of samples drawn from East Pakistan (Bangladesh), West Bengal, Uttar Pradesh and Orissa and indicated the possibility of at least three stocks distinguishable by the relative size of the body; one stock co-extensive from East Pakistan through West Bengal to Orissa coast, another from East Pakistan and Orissa, and a third from Uttar Pradesh. Pillay (1957b), reported that hilsa caught during September and October 1955 in the Hooghly have a relatively deeper body, compared to that from 1952 and 1953 and concluded that the fish caught in 1955 probably represented a stock different from the one that usually ascended the river. Pillay (1957b) through morphometric study of the hilsa population of the Hooghly and the Chilika lake, considered meristic characters like number of scutes, number of lateral line scales and the number of vertebrae and non-meristic characters like fork length, standard length, height of body, length of head, diameter of eye, length, height and thickness of caudal peduncle and thickness of body and concluded that there was only a single stock and the only distinguishable difference was in the age composition of fish.

Pillay et al. (1963) compared regression and D^2 analysis of body measurements as well as comparison of vertebral counts of the samples from the rivers Hooghly, Ganga, Padma, Brahmaputra, Barak, Godavari, Krishna, Cauvery and Narmada, the Chilika Lake, and the Saurashtra coast and suggested major river systems, the Chilika Lake, and the Saurashtra coast have their own stocks of hilsa and there is very little, if any, intermingling among them. Ghosh (1967), while examining the fishery at Allahabad, suggested that the stocks of hilsa at Allahabad are heterogeneous in nature and the Yamuna stock was endemic, probably also heterogeneous and was supplemented by a migratory stock. He indicated that difference in stock of the upper Ganga identified by Pillay et al. (1963) may perhaps be the Yamuna stock with a small range of migration within the local waters. Ghosh et al. (1968) examined samples from six centers in the Gangetic system covering the rivers Ganga and Padma and distinguished them on the basis of height of body in to three forms 'slender', 'broad', and 'broader' hilsa and concluded that all the three sub-populations are widely distributed in the entire stretch from Allahabad on the Ganga to Lalgola on the Padma. They were also of the opinion that each sub-population may occupy a separate spawning ground and therefore, at the spawning season the intermingling would be negligible, or absent. It was seen that the dominant 'broad' forms of Allahabad were replaced by the 'broader' forms at Varanasi and Buxar, which are localities located east of Allahabad. The 'slender' form dominates at Bagalpur, and was replaced by the 'broad' forms at Rajmehal, which in turn was replaced by the 'broader' type at Lalgola on river Padma. With regard to the Chilika population, Jhingran and Natarajan (1966) observed that winter/ spring and monsoon samples did not indicate any significant differences suggesting homogeneity. Ramakrishnaiah (1972) based on the number of scutes and vertebrae, concluded that the monsoon and winter/spring stocks of the lake are homogeneous. Rao (1969) examined the juveniles of different centers on the Godavari estuary and found significant differences between the year classes in respect of the number of pectoral fin rays and number of vertebrae, height and head length. Biometric analysis carried out by Shafi et al. (1977b) confirmed the identity of *Jatka* as juveniles of hilsa. Quddus (1982) examined samples from the rivers Padma, Meghna, Jamuna and Dhaleswari of Bangladesh and bifurcated the samples as 'broad' and 'slender' types. The possibility of presence of three eco-types was supported by Dutt (1966). Melvin (1984) suggested that, in Bay of Bengal, hilsa may represent assemblage of heterogeneous groups from different rivers in India, Bangladesh and Myanmar. Narejo et al. (2008) made a comparative study based on river Indus hilsa reveling significant differences in six morphometric measurements (total length, standard length, fork length, head length, eye diameter and girth) and seven meristic characters (total number of scutes, pre pelvic scutes, post pelvic scutes, dorsal fin rays, pectoral fin rays, pelvic fin rays and anal fin rays).

The review of works on stock delineation of hilsa indicate that several studies have been made on the traditional morphometric and meristic characters, however, studies based on truss morphometry is still lacking. Truss based morphometric studies to discriminate the stocks have been applied in other clupeids. Melvin et al.

(1992) revealed usefulness of meristic and morphometric characters in discriminating populations of American shad (*A. sapidissima*) inhabiting a marine environment. Besides the morphometric study, Quddus (1983) examined the two types for differences in biological features and found different spawning seasons; the broad ones spawn during monsoon and the slender ones during winter. The broad type grew faster and attained greater length at each age as compared to the slender type. In the light of these observations he suggested that the populations consist of two subspecies of *T. ilisha*, but recommended studies of biochemical composition, electrophoresis analysis, blood characteristics and genetics of these two types, before coming to any conclusion regarding the specific identity of the species. Referring to the total lack of knowledge on the migration of hilsa at sea, Melvin (1984) was of the opinion that the large concentration of hilsa in the Bay of Bengal may be indigenous to the rivers of Bangladesh or that they may represent a heterogeneous stock of fish from many rivers of India, Bangladesh and Burma. In the latter case, the respective stocks may be returning to their natal rivers for spawning.

Milton and Chenery (2001) made a comprehensive study of the stock structure of hilsa with otolith microchemistry by examining trace element composition in the otolith of hilsa with laser-ablation inductively coupled plasma mass spectrometry in conjunction with complementary genetic and morphometric studies. The otoliths of fish from 19 collections at 13 sites in Bangladesh and 6 collections at 4 sites from elsewhere within hilsa's range of distribution (Kuwait, south east India, Myanmar and Sumatra) were analyzed for 8 trace elements. When these data were analyzed separately, there were significant differences in otolith composition among sites. However, when both years' data were analyzed together, there were few significant differences among sites and some sites separated by hundreds of kilometers that were sampled in different seasons and years had similar compositions. Repeat samples from 5 sites (4 in Bangladesh) showed that differences in otolith composition at a single site were significant and of similar magnitude to that found among sites. The results supported the conclusion from allozyme studies that there is extensive movement and mixing of hilsa throughout Bangladesh and therefore the population should be managed as a single stock. Genetic and otolith data showed that hilsa from south east India and Myanmar were not significantly different from that collected from coastal waters of Bangladesh and suggested that hilsa in the Bay of Bengal were a single stock. Both methods also separated the fish from Sumatra and Kuwait, providing strong evidence of separate stocks in those regions. In contrast, morphometric studies separate fish from several nearby sites in Bangladesh, but these differences are likely to be largely due to phenotypic variability and are unlikely to be genetically based.

Genetic variations

Studies relevant to genetic variations conducted so far in its natural range of habitats have led to different inferences. Using RAPD and allozyme markers, it has been reported that hilsa in marine and freshwaters are from different gene pools in Bangladesh. Allozyme profiling of the fish did not exhibit significant heterogeneity among the population existing in Brahmaputra, Padma-Ganga at Allahabad, Varanasi and Hooghly. There has not been any evidence of genetic heterogeneity between Indian and Bangladesh samples and the gene pool is shared with that in the Bay of Bengal. Significant differences were not detected in populations within Bangladesh or within the Bay of Bengal (Bangladesh, Southeastern India and Myanmar) while significant differences occurred among Kuwait, Bangladesh and Indonesia. Some other studies based on genetic distance values (through RAPD analysis) reported that Narmada and Hooghly populations share same gene pool but Allahabad and Narmada populations are different. Lal et al. (2004) used allozyme to study the hilsa populations from the Brahmaputra, Padma, Ganga and Hooghly rivers and Feeder Canal at Farakka to conclude that the populations from these rivers did not differ significantly, though a high level of genetic variation was observed. The results indicated panmictic population, possibly due to mixing of populations that ascends through Jamuna in Bangladesh to Brahmaputra and Padma and also with Hooghly hilsa through small interconnecting rivers like Jalangi and Churni, etc., which is also supported by the inference drawn from tagging experiments (Anon, 1996). Salini et al. (2004) used allozyme and morphometric analysis to discriminate hilsa populations and did not find significant differences in allele frequencies in populations within Bangladesh or within the Bay of Bengal. Significant differences in allele frequencies occurred among Kuwait, Bangladesh and Indonesia specimens. Both these studies using allozyme, genetic and otolith data showed that hilsa from south east India and Myanmar were not significantly different from coastal areas of Bangladesh and suggesting hilsa in the Bay of Bengal are of single genetic stock. However, all these methods separated fish from Indonesia-Sumatra and Kuwait from other sites, providing strong evidence of separate stocks in those regions. (Brahmane et al., 2006) analyzed the populations of hilsa from different locations in rivers Ganga (Beniagram and Lalgola), Yamuna (Allahabad), Hooghly (Nawabganj), Bhagirathi (Feeder canal) and Narmada using RAPD. The UPGMA dendrogram based on genetic distance Nei (1978) indicated segregation of *T. ilisha* populations into two clusters. The populations from Allahabad, Beniagram and Lalgola from Yamuna and Ganga formed one cluster and the other cluster was of populations from Feeder canal, Nawabganj on rivers Bhagirathi and Hooghly and Bhadbhut from river Narmada (Fig. 30).

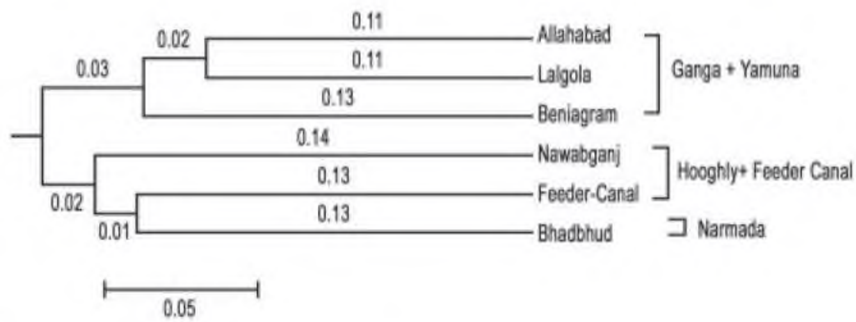


Fig. 30. Result of RAPD delineated hilsa populations from the Ganga, Yamuna, Hooghly, and Narmada rivers. Source: Brahmane, et al. (2006)

Rahman and Nævdal (2000) reported five polymorphic loci in hilsa samples collected from Chandpur region (lower and upper Meghna and Dhaleswari river), Barguna region (Paira, Bishkhali and Patharghata coast) and the Bay of Bengal (near the Cox's Bazar and Chittagong coast). Significant heterogeneity was found between the Chandpur-Cox's Bazar and Barguna-Cox's Bazar population pairs, but no heterogeneity was observed between the Chandpur-Barguna population pair. Therefore, they concluded that there were two gene pools of hilsa in Bangladesh waters. These results were in contrast with Dahle et al. (1997), who claimed that there were three discriminating populations of hilsa shad in Bangladesh waters such as

Chandpur (Meghna river), Barguna (brackish water, estuarine) and Cox's Bazar (sea water). Brahmane et al. (2013) reported free flow of gene pool and mixing in hilsa between Ganga and Hooghly rivers population using mitochondrial DNA Cytochrome *b* gene nucleotide sequence analysis. Using RAPD markers from the Hilsa of Padma and Meghna Rivers Dahle et al. (1997) and Shifat et al. (2003) found that Padma populations were genetically distant from the Meghna populations. Mazumder and Alam (2009) observed significant differentiation between the riverine and marine (Cox's Bazar) populations, but not between the marine and of the estuarine popupations. They concluded that there are three stocks of hilsa with a substantial level of inter-population genetic divergence among river, estuarine and marine populations. However, more than one gene pool in *T. ilisha* samples in Bangladesh were observed by Rahman and Nævdal (2000), with deviations in the allele frequencies for samples in the marine environment from freshwater and estuarine environment through analysis of enzymes and general muscle proteins. The notion of a single population migrating to Ganga and Hooghly rivers through the estuaries for spawning and breeding was supported by the mtDNA cytochrome b based genetic studies by Brahmane et al. (2013). Behera et al. (2012) analyzed hilsa samples collected from three different sites, river Ganga (Bay of Bengal origin) and two sites from Nuapada and Ukai reservoir (Arabian sea origin) for population structuring and genetic diversity using mitochondrial DNA Cytochrome *b* gene sequence analysis. Phylogenetic analysis revealed that the Hilsa of Bay of Bengal origin and Arabian Sea origin formed two distinct clusters (Fig. 31).

Despite the need for reliable identification of management units of the same species, stock

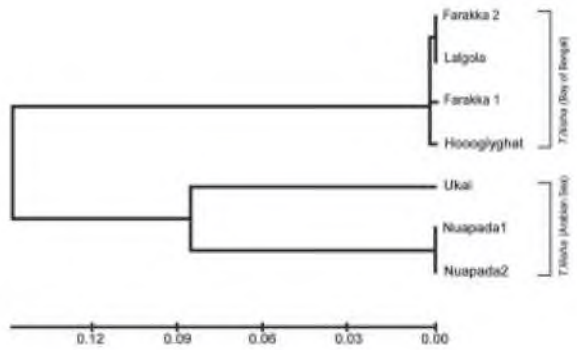


Fig.31. Phylogenetic tree showing two clusters of hilsa from Bay of Bengal and Arabian Sea. Source : Behera, et al. (2012)

identification cannot be accomplished with a single technique. Combining the results obtained with several techniques may provide considerable insight to the possible stock structure of a species. The ability to readily characterize the identity an individual fish or group of fish taken in a particular area and/or time, to a particular stock remains a major challenge and will always be probabilistic in lacking a technique or protocol that unambiguously identifies the origin of individual fish. Thus the stock character of the fish is still to be clearly delineated as to the existence of different stocks or there is only a single stock as evidence to rule or rule out such difference. There is also no conclusive information on the biological and morphological similarity or difference in hilsa. Use of genetic markers with more resolving power to detect genome wide variation and insight into pattern of gene flow can settle these unanswered questions. Therefore, a holistic approach to fish stock identification is highly desirable owing to the limitations and conditions associated with any particular method and the requirements of fishery management for separating units based on genotypic or phenotypic differences.

NUTRIENT COMPOSITION

Analyzing biochemical composition of fish is important to determine its nutritive value and physiological condition (Chandrasekhar et al., 2004; Ali et al., 2005). Moisture, fat, proteins, minerals and vitamins are the main composition of fish meat. Biochemical composition of fish depends on species, size, sexual condition, physical activity and feeding (Weatherly and Gills, 1987) and on food and habitat, besides seasonal changes (Sankar et al., 2010). The muscle architecture of hilsa has been studied by Nowsad (2010). There are two bundles of muscles on each side of the vertebral column and each of the bundles is further separated into an upper mass above the horizontal axial septum and a ventral mass below this septum. In between the upper and lower bundle mass, along the axial septum, a thick sheet of dark muscle is present, spreading widely on the surface beneath the skin but extending conically up to back bone. Abdominal portion of lower bundles are devoid of pin bones. Most of the muscle tissue is white (65-70%). White muscles have lower level of lipids, haemoglobin, glycogen and vitamins compared to dark muscles. The dark muscle, about 30 to 35% of total muscle, is located just beneath the skin, originates from the base of caudal region and extends along the horizontal axial septum up to cranium. The darkness in muscles originates from haemoglobin with myofibrillar proteins, called myoglobin. Dark muscles are generally devoid of pin bones and characterized with higher levels of lipids, haemoglobin, glycogen and vitamins. Dark muscle also contains high trimethylamine oxide and amino acids. The dark muscle primarily functions as a cruising muscle, for slow continuous movement, characteristics of migratory species (Huss, 1988). Knowledge on proximate composition, amino acid profile, fatty acid profile, vitamin and mineral content of the fish is important for understanding its nutrient requirement in development of suitable feed for larvae, juveniles, fingerlings and adults for rearing them in captivity. In addition to that, this information will also provide insight for incorporating specific bio-molecules in the feed to maintain organoleptic taste.

The Changes in the nutritional profile of Godavari hilsa during its migration from Bay of Bengal to the river Godavari has been studied by Rao et al. (2012) and reported higher protein content in

Table 22. Proximate composition of hilsa during anadromous migration to river Godavari.

Proximate composition	Marine (Bay of Bengal)	Brackish water (River mouth)	Freshwater (river Godavari)			
	June	July	August	September	October	November
Moisture (%)	63.50	62.31	64.63	66.30	69.29	66.64
Protein (%)	22.69	18.14	19.92	21.53	20.15	22.38
Fat (%)	12.40 (33.97)	17.38 (46.11)	14.51 (41.02)	11.18 (33.18)	9.83 (32)	8.78 (26.32)
Ash (%)	1.43	1.68	1.03	1.15	0.73	1.66

Source: Rao et al. (2012), Values in parentheses indicates fat value on dry matter basis

Table 23. Biochemical composition of hilsa from upstream Hooghly estuary during pre-monsoon period.

Composition	Juvenile (10g+)	Small (200 g+)	Medium (500 g+)	Large (800 g+)
Moisture (%)	83.91 (0.12)	74.36 (1.29)	57.4 (0.66)	68.04 (1.32)
Lipid (%)	1.32 (0.28)	1.99 (0.30)	2.48 (0.25)	7.82 (0.07)
Crude protein (%)	59.9 (0.22)	15.39 (0.57)	21.23 (0.23)	15.58 (0.33)
Carbohydrate (%)	1.54 (0.03)	2.60 (0.21)	7.18 (0.06)	3.14 (0.07)
Callory value (Cal. g/kg)	456.0 (3.61)	143.83 (2.41)	260.0 (3.23)	196.81 (0.79)

Source : Nath and Banerji (2012), Values in parenthesis indicate standard deviation

marine samples (22.69%) in comparison to brackish water samples (18.14%) and freshwater hilsa from Godavari (19.92 to 22.38%) as shown in Table 22. Ash content was marginally higher in the brackish water hilsa (1.68%) than in marine hilsa (1.43%) and freshwater Godavari hilsa (0.73 to 1.66%). However, reported wide variation in fat content during its anadromous migration. The fat content in the marine hilsa was 12.4% and it increased to 17.3% in brackish water hilsa and gradually decreased when in freshwater (14.51 to 8.78%), suggesting that hilsa gains fat in the brackish water environment. The Godavari hilsa showed decreasing fat content with time, possibly due to consumption of enormous amount of energy during the migratory movement. Jonsson et al. (1997) reported decrease in lipid content during the course of upward migration of Atlantic salmon. Body lipid decreased by 30-40% during the period of re-entry of Arctic charr to freshwater from sea and the female fish lost 80% of their body lipids during spawning (Josrgensen et al., 1997). Boetius and Boetius (1985) observed that the success of migration of European eel is heavily dependent on the quantity of lipids stored during their growth phase. Fat content found to vary with period of migration of the hilsa and this might be the reason for the different average fat values (7.5% to 26.93%) reported in *T. ilisha* by several researchers who might have sampled the fish at different times of migration (Pillay et al., 1963; Chandrasekhar et al. 1994; Rahman et al., 1999; Majumdar and Basu, 2009).

A 100 g hilsa contains 22 g protein, 19.5 g fat, 180 mg calcium and 250 mg of phosphorus along with other nutrients and fat content of 20% in Mahanadi river mouth, while it was lower in Narmada (Mohanty et al. 2011). The water quality parameters like salinity, temperature, water pressure, seasons and feeding habits contribute to the changes in the proximate composition. Different regions of the habitat contain different types of food and make proximate composition different (Kamp, 1993; Shamim et al., 2011). Nath and Banerji (2012) estimated the biochemical composition of hilsa during upstream and downstream migration as given in Table 23 and 24.

Table 24. Biochemical composition of hilsa collected from downstream and upstream of Hooghly estuarine system during monsoon.

Composition	Downstream		Upstream
	Small (200 g+)	Medium (500 g+)	Large (800 g+)
Moisture (%)	57.66 (0.41)	45.77 (0.42)	58.70 (0.17)
Lipid (%)	14.45 (0.14)	20.85 (0.17)	13.71 (0.14)
Crude protein (%)	17.79 (0.09)	11.0 (0.33)	13.23 (0.15)
Carbohydrate (%)	3.45 (0.07)	5.34 (0.33)	3.41 (0.16)
Cal. value (Cal. g/l)	291.37 (1.64)	427.32 (1.55)	304.98 (0.29)

Source : Nath and Banerji (2012), Values in parenthesis indicate standard deviation

Protein content in smaller hilsa was found to be higher than that in the medium and large hilsa during the monsoon Nath and Banerji (2012). In general, except in juveniles, protein values did not vary much Nath and Banerji (2012). The adult fishes have low protein content during monsoon period, which indicated that they consumed less food or it may be due to starvation and their protein content did not increase (Lucas and Baras, 2001). Chandrashekhar et al. (2004) also opined that significant difference ($p<0.05$) in protein values were observed in large fish groups of upstream and between medium sized group of upstream and downstream during pre-monsoon and monsoon period. In Salmon, protein fat ratio varied during migration in such a way that these fishes utilized more fat than protein for better growth and reproduction (Hillestad and Johnsen, 1994). In tuna and mackerel also fat replaces the protein in some cases for energy utilization (Mannan et al., 1961). Similarly, low protein fat ratios were found in hilsa during monsoon season at Hooghly estuary, which indicated their preparation for spawning migration (Nath and Banerji, 2012). The crude protein content varies at parts of the body sampled from different habitats (Fig. 32). For example, the crude protein estimates of hilsa from Chittagong and Khulna regions of Bangladesh showed that ventral portion of the fish from Chittagong region and dorsal portion of the fish from Khulna region contained maximum amount of protein (Shamim et al., 2011). Rao et al. (2012) also reported region wise difference in protein content of marine (22.69%) and brackish water hilsa (18.14%).

Lipids are the third major proximate component of fish and its variation is greater than protein. The composition of lipid can vary with feed intake and seasonal variation and several other factors. Among the poly-unsaturated fatty acids, eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) are the major components. In several fish species, fat builds up during feeding season and its proportion decrease substantially during spawning season. Fish with

Table 25. Percentage of fatty acids in different weight groups of hilsa collected from upstream and downstream stations of Hooghly estuary during pre-monsoon and monsoon period.

Constituents	Pre-monsoon Upstream				Monsoon Downstream		
	Juvenile	Small	Medium	Large	Large	Small	Medium
Lipid (%)	1.32	1.99	2.48	7.82	13.71	14.45	20.85
Fatty acid (%)							
SFA	49.9	55.8	50.74	49.9	53.01	52.7	57.32
UFA	49.6	43.75	48.4	49.4	46.8	46.8	42.88
Mono UFA	22.8	29.05	30.9	34.05	36.7	34.7	34.73
PUFA	26.8	14.7	17.5	12.7	10.1	12.1	8.15
UFA/SFA	0.99	0.78	0.95	0.99	0.883	0.658	0.748
PUFA/SFA	0.54	0.26	0.34	0.25	0.19	0.23	0.14
DHA / EPA1	0.96	0.39	0.62	0.25	0.18	0.15	0.17

Source: Nath and Banerji (2012)

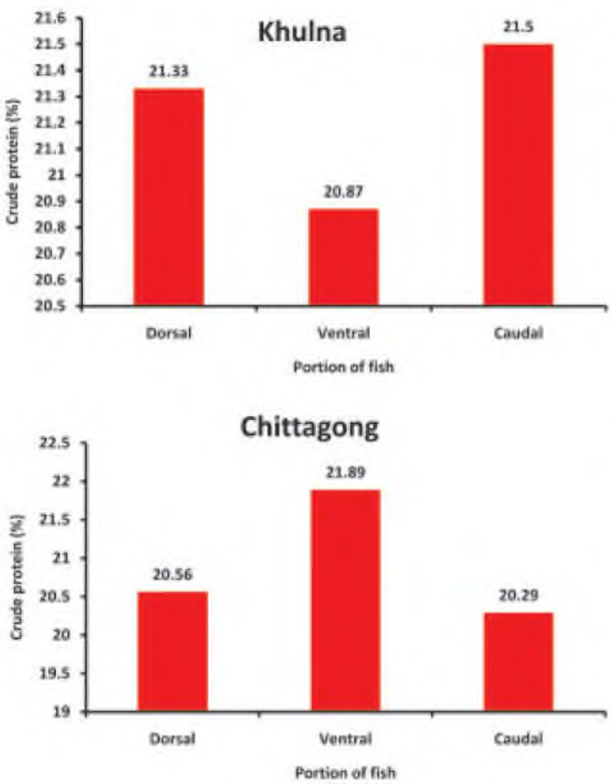


Fig. 32. Variation of crude protein content (%) from different portions of fish. Source: Shamim et al. (2011)

fat content lower than 0.5% and as high as 18-20% is common. Hilsa contains high amount of EPA and DHA. Migratory species like salmon showed variation in lipid content during migration (Jonsson et al., 1997). Boetius and Boetius (1985) observed that the success of migration of European eels is highly dependent on the quantity of lipids stored during their growth phase. According to Rao et al. (2012) the fat gradually decreased in Godavari hilsa (14.51 to 8.78%) en-root its migration. Higher amount of saturated fatty acids in hilsa (5844.5 mg/100 g fish) and 3345 mg/100 g of palmitic acid contributed have been reported by Edirisinghe et al. (1998) from Sri Lanka. Small hilsa from upstream and large fishes from downstream were found to possess PUFA ranging between 10.1 to 17.5%. Ratio of DHA/ EPA was found to be maximum (0.96) in juvenile groups, while the ratio was higher (3.2-7.0) in upstream hilsa during pre-monsoon period as compared to that of monsoon period (2.5-3.0). Large upstream hilsa showed omega-3/ omega-6 ratio of 2.66 and downstream small and medium size groups showed ratios of 3.0 and 2.5 respectively (Nath and Banerji, 2012). Table 25 shows the fatty acid composition in different weight groups of hilsa collected from upstream and downstream of Hooghly estuary during pre-monsoon (March-May) and monsoon (July-September) as given by Nath and Banerji (2012).

Ackman (1994) reported that freshwater and tropical oceanic fishes commonly contain large percentage of omega 6 PUFA; especially arachidonic acid. This slightly differs with the findings of Nath and Banerji (2012) who reported higher percentage of omega 3 PUFA (Table 25). Rao et al. (2012) stated that the fat content in the marine hilsa is 12.4% and it increased to 17.3% in brackish water hilsa. Changes in fatty acid content in hilsa during migratory phase as given by Rao et al. (2012) are given in Table 26.

Ash content was marginally higher in the brackish water hilsa (1.68%) than in marine hilsa (1.43%) and Godavari river hilsa (Rao et al., 2012). Minerals play an important role in osmoregulation and sexual maturation of fish. In Godavari hilsa it has been found that potassium, calcium and phosphorus levels were relatively higher. Iron content was almost similar in marine and Godavari hilsa (Rao et al., 2012). Shamim et al. (2011) reported that the percentage of ash content was maximum in ventral portion of fish body from the Khulna region (1.55) and lowest in dorsal portion of fish body from the Khulna region (1.03).

Table 26. Changes in saturated (SFA) and unsaturated (USFA) fats during migration of hilsa from marine (Bay of Bengal) to freshwater (River Godavari).

Source of hilsa	SFA	USFA
Marine (Bay of Bengal	36.03	63.98
Brackish water (Godavari)	36.76	63.14
Freshwater (river Godavari)	24.98	75.02

Source: Rao et al. (2012), SFA: Saturated fatty acid; USFA: Unsaturated fatty acid.

Nutrient profile of Ganga hilsa

Mohanty et al. (2012) studied the fatty acid profile of *T. ilisha* from river Ganga. The crude fat content of small, medium and large size hilsa was found to be 6.74–9.43, 8.94–12.56 and 11.25–17.87%, respectively (Table 27). Quantitatively, oil content of hilsa is significantly higher than many of the riverine and estuarine fishes.

The total Mono Unsaturated Fatty Acids (MUFAs) in small, medium and large sized hilsa were 31.60 $\pm$ 0.19, 35.36 $\pm$ 0.20 and 27.59 $\pm$ 0.18 %, respectively (Table 27). MUFAs decreased with size of the fish and it was higher in medium sized fish. Oleic acid (OA) (C18:1; n-9) was the major MUFA in different size groups ranging from 25.42 to 30.66%. The total Poly Unsaturated Fatty Acids (PUFAs) in small, medium and large size hilsa were 23.78 $\pm$ 0.08, 22.11 $\pm$ 0.25 and 14.75 $\pm$ 0.39 %, respectively (Table 28). The PUFA of all size groups composed of EPA (C20:5; n-3) followed by DHA (C22:6; n-3), arachidonic acid (AA) (C2 0:4; n-6) and a-linolenic acid (ALA) (C18:3). The maximum amount of EPA was found in the large sized hilsa (8.22 $\pm$ 0.25 %), followed by medium (2.87 $\pm$ 0.09 %) and small (2.49 $\pm$ 0.03 %), where as highest amount of DHA was present in medium sized hilsa followed by small and large sized hilsa. The total amount of EPA and DHA content in three different sizes of hilsa ranged between 10.24 and 11.83 % with highest level of DHA + EPA (11.83 $\pm$ 0.09 %) was found in medium size fish. ω-3 fatty acids (EPA and DHA) play an important role in the fortification of the myelin sheath.

Mohanty et al. (2012) studied the total percentage of essential amino acids in different size groups of hilsa (small, medium and large) and found that 39.42%, 42.3% and 48.58% of essential amino acids are present in small, medium and large sized hilsa, respectively. Similarly, the non- essential amino acids for small, medium and large sized hilsa was found to be 52.44%, 55.94% and 49.79% respectively (Table 29).

Nutrient profile of Bangladesh hilsa

Majumdar and Basu (2009) has studied the macro and micro-nutrient constituents of *T. ilisha*. The average proximate composition recorded were: moisture 68.16%, ash 1.42%, protein 16.27%,

Table 27. Seasonal variation in crude fat content of *T. ilisha* (g/100 g of wet muscle)

Size/season	July-October	November-February	March-June
Small (32.38 $\pm$ 1.93 cm; 200-400g)	9.43 $\pm$ 0.42a	6.74 $\pm$ 0.53b	7.56 $\pm$ 0.24b
Medium (38.98 $\pm$ 1.77 cm; 800-1000g)	12.56 $\pm$ 0.83a	8. 94 $\pm$ 0.70b	9.91 $\pm$ 0.70b
Large (45.10 $\pm$ 0.89 cm; 1400-1600g)	17.87 $\pm$ 0.51a	11.25 $\pm$ 0.29b	14.73 $\pm$ 0.80c

Values are presented as mean $\pm$ standard deviation; different letters (in superscript) within a row correspond to statistical differences ($p<0.05$) between size groups. Source: Mohanty et al. (2012)

Table 28. Fatty acid composition (% of total fatty acid) of *T. ilisha*

Fatty acid	Small size	Medium size	Large size
Saturated			
8:0 (%)	0.05 ± 0.04[a]	0.03 ± 0.03[a]	0.03 ± 0.01[a]
10:0 (%)	0.06 ± 0.02[a]	0.05 ± 0.01[a]	0.02 ± 0.01[b]
12:0 (%)	0.41 ± 0.01[a]	0.37 ± 0.23[a]	0.09 ± 0.03[b]
13:0 (%)	0.24 ± 0.25[a]	0.05 ± 0.01[a]	0.02 ± 0.01[a]
14:0 (%)	38.78 ± 0.12[a]	37.77 ± 0.02[b]	9.67 ± 0.48[b]
15:0 (%)	1.69 ± 0.04[a]	1.48 ± 0.01[b]	0.34 ± 0.12[c]
16:0 (%)	0.81 ± 0.05[a]	0.21 ± 0.06[b]	38.26 ± 0.05[c]
17:0 (%)	0.82 ± 0.03[a]	1.05 ± 0.03[b]	0.19 ± 0.05[c]
18:0 (%)	0.24 ± 0.02[a]	0.26 ± 0.06[a]	8.86 ± 0.16[b]
20:0 (%)	0.62 ± 0.06[a]	0.67 ± 0.03[b]	0.20 ± 0.02[c]
22:0 (%)	0.48 ± 0.09[a]	0.45 ± 0.02[a]	0.22 ± 0.09[b]
24:0 (%)	0.43 ± 0.02[a]	0.44 ± 0.04[a]	0.11 ± 0.05[b]
ΣSFA (%)	44.64 ± 0.09[a]	42.82 ± 0.07[b]	57.99 ± 0.15[c]
Monounsaturated			
14:1 (%)	0.26 ± 0.05[a]	0.18 ± 0.08[a]	0.07 ± 0.04[b]
15:1 (%)	0.08 ± 0.02[a]	0.05 ± 0.02[a]	0.01 ± 0.01[b]
16:1n-7 (%)	0.06 ± 0.01[a]	0.48 ± 0.05[b]	0.22 ± 0.06[c]
17:1	0.25 ± 0.08[a]	0.29 ± 0.09[a]	0.07 ± 0.05[b]
18:1n-9 (%)	26.55 ± 0.51[a]	30.66 ± 0.19[b]	25.42 ± 0.25[c]
20:1n-9 (%)	3.47 ± 0.06[a]	2.27 ± 0.36[b]	1.23 ± 0.40[c]
22:1n-9 (%)	0.38 ± 0.06[a]	0.64 ± 0.02[b]	0.09 ± 0.04[c]
24:1 (%)	0.55 ± 0.13[a]	0.78 ± 0.05[b]	0.20 ± 0.13[c]
ΣMUFA (%)	31.60 ± 0.19[a]	35.36 ± 0.20[b]	27.59 ± 0.18[c]
Polyunsaturated			
18:2n-6 (%)	0.66 ± 0.12[a]	0.88 ± 0.03[b]	0.29 ± 0.45[a]
18:2tr (%)	2.66 ± 0.11[a]	1.84 ± 0.66[b]	0.88 ± 0.09[c]
20:2n-6 (%)	0.13 ± 0.02[a]	0.12 ± 0.03[a]	0.03 ± 0.02[b]
22:2n-6 (%)	0.07 ± 0.01[a]	0.07 ± 0.01[a]	0.15 ± 0.04[a]
18:3n-3 (%)	2.61 ± 0.06[a]	2.23 ± 0.04[b]	0.59 ± 0.13[c]
18:3tr (%)	0.86 ± 0.16[a]	0.68 ± 0.05[a]	0.74 ± 0.72[a]
20:3n-6 (%)	1.11 ± 0.06[a]	0.14 ± 0.004[b]	0.08 ± 0.04[b]
20:3 and 21 (%)	0.13 ± 0.02[a]	0.17 ± 0.03[b]	0.03 ± 0.09[c]
20:4n-6 (%)	4.66 ± 0.03[a]	4.14 ± 0.06[b]	1.21 ± 0.33[c]
20:5n-3 (%)	2.49 ± 0.03[a]	2.87 ± 0.09[b]	8.22 ± 0.25[c]
22:6n-3 (%)	8.41 ± 0.01[a]	8.95 ± 0.03[b]	2.02 ± 0.42[c]
ΣPUFA (%)	23.78 ± 0.08[a]	22.11 ± 0.25[b]	14.75 ± 0.39[c]
Σ ω -3 (%)	13.51 ± 0.09[a]	14.06 ± 0.05[b]	10.83 ± 0.68[c]
Σ ω -6 (%)	6.62 ± 0.12[a]	5.36 ± 0.09[b]	1.76 ± 0.37[c]
EPA + DHA (%)	10.90 ± 0.03[a]	11.83 ± 0.09[b]	10.24 ± 0.57[a]
Σ ω -3/Σ ω -6	2.18 ± 0.26[a]	2.62 ± 0.04[a]	6.41 ± 1.86[b]
ΣPUFA/ΣSFA	0.54 ± 0.01[a]	0.52 ± 0.02[a]	0.25 ± 0.02[b]

Values are mean ± standard deviation; different letters (in superscript) within a row correspond to statistical differences ($p < 0.05$) between size groups. SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids; EPA eicosapentaenoic acid; DHA: docosahexaenoic acid. Source: Mohanty et al. (2012)

Table 29. Amino acid profile of T. ilisha.

Amino acid	Small size	Medium size (% of total amino acid)	Large size
Essential amino acids			
Threonine	ND	6.32 ±0.17[a]	7.10 ±0.03[a]
Valine	6.58 ± 0.81[a]	6.35 ± 0.21a	5.80 ±0.81a
Methionine	3.30 ±0.29[a]	1.63 ±0.10[b]	2.72 ±0.02[c]
Iso leucine	5.35 ±0.12[a]	6.20 ±0.21[b]	4.69 ±0.58[a]
Leucine	9.25 ±0.33[a]	9.33 ±0.35[a]	8.03 ±0.06[b]
Phenylalanine	4.16 ±0.14[a]	3.71 ±0.42[b]	3.43 ±0.38[b]
Histidine	6.31 ±0.10[a]	5.47 ±0.41[b]	5.94 ±0.21[a]
Lysine	3.22 ±0.03[a]	2.35 ±0.25[b]	10.15 ±0.05[c]
Arginine	1.25 ±0.13[a]	0.94 ±0.03[b]	0.72 ±0.01[c]
ΣEAA	39.42	42.3	48.58
Non-essential amino acids			
Aspartic acid	10.48 ± 0.04[a]	11.25 ±0.40[b]	10.21 ± 0.06[c]
Serine	6.56 ± 0.13[a]	7.02 ±0.31[b]	5.99 ±0.13[c]
Glutamic acid	15.16 ± 0.47[a]	15.39 ±0.22[a]	13.06 ±0.06[b]
Glycine	8.46 ± 0.39[a]	9.01 ±0.21[b]	8.22 ±0.25[a]
Alanine	9.34 ± 0.28[a]	9.59 ±0.15[a]	8.45 ±0.04[b]
Tyrosine	1.92 ± 0.54[a]	1.39 ±0.16[a]	0.84 ±0.16[b]
Proline	0.20 ± 0.05[a]	1.34 ±0.39[b]	0.91 ±0.10[b]
Cysteine	0.32 ± 0.03[a]	0.95 ±0.04[b]	2.11 ±0.06[c]
ΣNEAA	52.44	55.94	49.79
EAA/NEAA	0.75	0.76	0.98

Values are shown as average ± standard deviation.
ND- not detected, EAA- essential amino acid, NEAA- non essential amino acid
Source: Mohanty et al. (2012)

fat 12.04%, calcium 55.09%, phosphorous 184.58%, sodium 66.10% and potassium 179.95%. The maximum moisture content in January was (74.22%) when the average weight of the sample was 357.83 g and the minimum was in September (58.82%) when the average weight of the sample was 788.35 g (Table 30). The lowest fat content was recorded during January to April, whereas, the maximum was during July to September. Rest of the period, the average fat content was 11.45%. The proportion of calcium and phosphorous in the flesh of hilsa increased with increase in size. On the other hand, sodium, decreased considerably with growth of the fish, whereas no definite trend of variation was observed in potassium content of the fish.

Table 29. Proximate composition of hilsa estimated month-wise

Month	Size (cm)	Av. wt. (g)	Moisture (%)	Ash (%)	Fat (%)	Protein (%)
October 2006	29.1 - 48.9	654.62	67.44±1.4	1.50±0.12	12.35±1.63	16.18±0.64
November	30.2 - 39.5	513.61	67.70±1.35	1.46±0.08	11.68±1.44	15.85±0.40
December	20.4 -23.9	220.40	69.95±1.50	1.62±0.52	10.38±1.22	16.08±0.86
January 2007	17.6 - 39.8	357.83	74.22±3.68	1.49±0.09	5.67±2.60	15.54±0.58
February	19.2 - 23.9	209.64	73.48±2.46	1.46±0.07	5.71±1.47	15.41±0.74
March	18.5 - 22.4	168.86	72.65±2.57	1.55±0.06	7.10±1.49	15.13±0.65
April	18.2 - 37.9	348.41	71.53±4.08	1.45±0.05	7.46±3.79	15.83±1.13
May	39.6 - 46.5	802.42	69.64±1.71	1.36±0.12	10.18±1.39	15.94±1.1
June	36.2 - 44.5	785.98	69.83±2.10	1.41±0.04	12.67±1.26	17.28±0.36
July	34.7 - 44.8	792.32	62.73±1.08	1.26±0.07	18.41±1.41	17.54±0.67
August	35.2 - 43.7	799.08	59.89±1.88	1.25±0.04	20.78±1.85	17.24±0.66
September	33.8 - 42.2	788.35	58.82±2.23	1.27±0.09	22.08±1.43	17.28±0.66

Source: Majumdar and Basu (2009)

SENSORY MECHANISM

Sensory mechanism, especially chemoreception and factors regulating them in fishes, in general, is poorly understood, although these are the cues that play important role in fish migration. With regard to hilsa, there is complete lack of information on the sensory mechanisms in place. The lateral line sensory receptors found chiefly in fishes is used to detect movement and vibration in the surrounding water. It serves an important role in orientation of fish. The lateral line system is visible as feeble line running lengthwise along each lateral side, from the vicinity of the opercula to the base of the caudal fin, hence the name 'lateral line'. In some species, the receptive organs of the lateral line have been modified to function as electroreceptor, which are organs used to detect electrical impulses (Weeg and Bass, 2002). The sensory ability is achieved via modified epithelial cells throughout the lateral line, known as hair cells, which respond to displacement caused by movement and transduce these signals into electrical impulses via excitatory synapses. Coombs et al. (2001) confirmed sensory function of the lateral line system for detection of vibrations made by prey and for orientation towards the source to begin predatory action.

Clupeid fishes have highly developed lateral line system on the head but, apart from a short branch behind the operculum, they have no well defined lateral line on the body. In describing the lateral line in herring (*Clupea harengus*), Allen et al. (1976) showed that it started to develop at length of 22-24 mm, some 4 to 6 weeks after hatching and was complete, just subsequent to metamorphosis, at about 40 mm. They did not observe the structure of neuromast organ within the canal and no further observation was made about the nature of the lateral line in clupeids. However, on the sprat (*Sprattus sprattus*), Best and Gray (1982) investigated the nerve supply to the neuromast in the infra-orbital canal of the lateral line, the number of hair cells and their orientation in relation to the axis of the canal. They also gave an account of the poor structure of the neuromast and copula. The development and distribution of the system of free (surface) neuromast in clupeids is also not well known, although it has been established that free neuromasts occur on the head and trunk of teleost embryos and larvae in general (Iwai, 1967). In clupeids, free neuromasts were recorded on the head of the adult pilchard (*Sardina pilchardus*) (Wohlfahert, 1937) and on the trunk of pilchard larvae (Blaxter, 1969). In the larvae of northern anchovy (*Engraulis mordax*), a row of free neuromast on the trunk and on the head, the number increasing in size (O' Connell, 1981).

Olfaction plays a vital role in fish for searching food, migration, predator, etc. (Hara, 1975, 1992). Olfactory system in fish is represented by the olfactory epithelium situated on the floor of nasal chamber. Many reports are available on the morpho-histology of olfactory organ in fishes (Zeiske et al., 1987, Hara and Zielinski, 1989; Hara et al., 1993; Bannister, 1965; Bertmar, 1973; Lowe and Macleod, 1974; Fisher et al., 1984; Hansen and Finger, 2000; Mana and Kawamura, 2002). The folding or lamellae of the olfactory epithelium increases the surface area of the epithelium as well as the sensitivities and efficacy of the olfactory organ (Zeiske et al., 1976). Of the two olfactory epithelia, the sensory epithelium exhibits various distribution patterns such as continuous, separated regularly by non-sensory epithelium, interspaced irregularly and scattered in islets (Hara, 1993). The olfactory epithelium also bears different sensory cells with different functional and structural entities of variable degrees of sensitivities to external stimuli (Yamamoto, 1982). The transduction of olfactory information occurs in the olfactory epithelium, a sheet of neurons and supporting cells that lines approximately half of the nasal cavity. The second olfactory epithelium, the non-neural epithelium is found at the external regions of the nasal cavity. In both the respiratory and olfactory epithelium, immunoglobulin's are secreted into the mucus, providing an initial defense against harmful antigens and the sustentacular cells contain enzymes (cytochrome P450s and others) that catabolize organic chemicals and other potentially damaging molecules that enter the nasal cavity (Sorensen and Stacey, 2004). There is no such information available with regard to hilsa.

Chemoreception

Olfactory organ of marine and migratory fishes possesses strong evidence of chemoreception. Most of the studies on olfactory chemoreception are on marine fish especially sharks and salmons. Salmon has been the most investigated fish species with regard to migration, homing, olfaction and chemo reception. The information available might be of use with regard to investigations on hilsa, as we do not have good knowledge of the mechanism in the fish. Olfaction is strong in salmon (Hasler and Wisby, 1951; Hasler et al., 1978). Hasler and Wisby (1951) hypothesized that, once in the vicinity of the estuary or entrance to river, salmon use chemical cues, unique to the stream, as a mechanism to home onto the entrance of the stream. Salmon swim up the rivers until they reach the very spawning ground that was their original birthplace (Moyle and Cech, 2004). Hasler et al. (1978) showed that the way salmon home on to rivers with precision was through olfactory senses. They further demonstrated that the smell of the river get imprinted in salmon when they transform into smolts, just before they migrate out to the sea. Homecoming salmon can also recognize characteristic smells in tributary streams as they move up the main river. In the sea, they use magneto-reception (Putman et al., 2013) to locate the general position of their native river and once close to the river, they use their sense of smell to home in on the river entrance and even their natal spawning ground. There are various theories about how this happens. One theory is that there are geomagnetic and chemical cues, which the salmon use to guide them back to their birthplace. The fish may be sensitive to the Earth's magnetic field, which might allow the fish to orient itself in the ocean, so it can navigate back to the estuary of its native stream. Putman et al. (2013) pointed out that Salmon returning to the river must detour to reach the mouth of the river. They found that the "drift" of the geomagnetic field correlated with the route the salmon chooses. Two separate hypotheses arose during the early research on salmon homing and each of this included olfaction (Brannon, 1982). One was that adult salmon could locate native sites by responding to pheromones released by juvenile conspecifics at the native river and along the migration route (Nordeng, 1971; 1977; Solomon, 1973). Other hypothesis was that, juvenile salmon imprinted on unique chemical characteristics (i.e., environmental odors) in water at their native site and locations during downstream outmigration and then returning adults used these to home (Hasler and Wisby, 1951; Wisby and Hasler, 1954; Harden Jones, 1968). Stream odors used for imprinting may include chemicals released by conspecifics or related individuals (i.e., hormones, pheromones), and recognition of such odors has been well documented (Groot et al., 1986; Moore and Scott, 1991; Courtenay et al., 1997 and 2001).

After several decades of laboratory and field experiments, olfactory imprinting is now the consensus among experts on homing mechanism used by anadromous salmonids (Hasler and Scholz, 1983; Dittman and Quinn, 1996; Nevitt and Dittman, 1999; Hino et al., 2009; Ueda, 2011 and 2012).

The olfactory imprinting hypothesis for salmon homing was first proposed by Hasler and Wisby (1951), based on behavioral experiments demonstrating that the fish can discriminate between the waters of different streams on the basis of odors. To test this hypothesis, Hasler and his colleagues exposed juvenile Coho salmon (*Onchorhynchus kisutch)* to one of two synthetic chemicals, morpholine or b-phenylethyl alcohol (PEA) and were able to attract the salmon into unfamiliar streams scented with one of these chemicals during their spawning migration, one and half year later (Cooper et al., 1976). Hasler and Scholz (1983) further proposed that the process of olfactory learning and homing is intimately linked to hormone levels at different life stages. Their studies with artificial odorants suggested that juvenile Coho salmon learn the odors of their home stream during parr-smolt transformation (PST), a developmental process characterized by physiological and behavioral changes, which prepare freshwater residents (parr) for life at sea (Hasler and Scholz, 1983; Nevitt et al., 1994; Dittman et al., 1996 and 1997). However there is considerable evidence of imprinting during multiple early life stages, including embryos, alevins, fry, and parr (Riddell and Leggett, 1981; Dickhoff and Sullivan, 1987; Courtenay, 1989; Dittman and Quinn, 1996). In fact, pre-smolt imprinting is essential for populations whose juveniles move rapidly to saltwater (Heard, 1996) and for populations that rear at locations downstream from spawning sites. The importance of the PST as a sensitive period for olfactory imprinting by Coho salmon has been confirmed using hatchery-reared Coho salmon exposed to the odorant PEA as embryos, parr or smolts (Dittman et al., 1996). Only salmon exposed to PEA as smolts were attracted as adults to water scented with PEA. These results are consistent with the general finding that salmon reared at one site but released from a second site prior to, or during, PST return as adults to the release site, not the rearing site (Donaldson and Allen, 1957; Jensen and Duncan, 1971).

Many of the changes that occur during the parr-smolt transformation are associated with surges in the plasma levels of the hormone thyroxine (Dickhoff and Sullivan, 1987) and these elevated thyroxine levels may be involved in olfactory learning (Hasler and Scholz, 1983). Scholz (1980) demonstrated that presmolt Coho salmon with artificially elevated thyroxine levels exposed to an odor were able to retain long-term memories of that odor, whereas untreated control fish could not. Consistent with this hypothesis, Morin et al. (1989a; 1989b; 1994), Morin and Doving (1992) found a period of enhanced olfactory sensitivity during the PST which coincided with increased thyroid activity and imprinting ability in Atlantic salmon (*Salmo salar*). In salmonids, imprinting events are apparently preceded by an increase in hormones produced by the thyroid gland and particularly by surges in thyroxine (T4) and triiodothyronine (T3). Thyroid hormone surges in juvenile salmonids have been associated with increased sensitivity and cell growth in the olfactory epithelium and with development of olfactory receptor neurons (Nevitt et al., 1994, Nevitt and Lema, 2002; Lema and Nevitt, 2004). Olfactory receptors detect and bind odor molecules such as amino acids or pheromones in a process broadly defined as chemoreception. Once bound, a biochemical process converts the odor signal to an electrical signal that is transmitted to the brain and specifically to the olfactory bulb, where memory is stored (Nevitt and Dittman, 1999). Additionally, the receptor neurons in the epithelium proliferate during thyroid surges and the cells themselves survive and remain sensitive to the imprinted chemicals (Dukes et al., 2004). The understanding, as described by Nevitt and Dittman (1999), is that olfactory imprinting involves memory storage in both the brain and the neural cells in the nasal epithelium. Johnstone et al. (2011) showed that olfactory genes are expressed differently among parr, smolts and adults in Atlantic salmon. In contrast, a landlocked population showed no differences in olfactory gene expression in the different life stages. That regulation of these genes is linked to physiological state and environmental cues. Whereas the anadromous populations must activate specific receptor cells to imprint these cues; prepare for saltwater entry and recall the home stream odors as adults, the life history of landlocked salmon does not appear to require these processes and hence these genes are not upregulated. Another process is 'sequential imprinting' which occurs in juveniles transition through physiological states and when they encounter novel odors associated with changes in ecological environmental conditions (Harden Jones, 1968; Brannon, 1982). Studies on juvenile salmonids transported for various distances, offered some insight on this process. Transport studies of Coho salmon (Solazzi et al., 1991) and Atlantic salmon (Gunnerød et al., 1988; Heggberget et al., 1991), for example, have shown that adult homing success is inversely related to juvenile transport distance from rearing sites. Similarly, juvenile salmon and Steelhead collected in mid-migration and then transported downstream tend to home at lower rates than control groups that remain in the migration corridor (Hansen and Jonsson, 1991; Bugert et al., 1997; Chapman et al., 1997; Keefer et al., 2008). In cases where fish are transported outside the stream (transport trucks), there was no imprinting opportunity and had very poor homing. It is evident that olfactory sensing plays a number of important roles in migratory fishes. It is not clear whether hilsa has such mechanisms assisting them in migration or homing. Investigations in this direction would result in assisting management of the hilsa, in its natural environment as well as under captivity in future programs.

Chemoattractants

The major reproductive events in the lives of fishes (maturation, ovulation and spawning) are temporally correlated with the changes in plasma levels of key reproductive hormones (gonadal steroids and prostaglandins) that should have pre disposed them (and their precursors and metabolites) to serve as hormonal pheromones. Of these, released androgenic and estrogenic steroids are likely candidate for pheromone function, because they should convey to conspecific information on both gender and reproductive status. There are information on detection and function of androgenic pheromones in Gold fish (Sorensen et al., 2005) and Atlantic salmon (Moore and Scott, 1991). Further, Sensitive and specific EOG responses to prostaglandins $F_{2\alpha}$ and its metabolites provide strong, though indirect, evidence that hormonal pheromones derived from F-series prostaglandins are widespread, particularly amongst Cypriniformes, Characiformes, and Salmoniformes (Stacey et al., 1994; Stacey and Sorenson, 2002; Laberge and Hara, 2003). Bile acids released by stream-resident fish have been suggested to serve as pheromone attractants for maturing adult Charr that frequently have an anadromous history. A number of studies

(Doving et al., 1980; Zhang et al., 2001) showed that Arctic charr and Lake charr release and detect various bile acids, which also induce behavioral responses (Jones and Hara, 1985). However, it remains to be seen that which specific bile acids released by Charrs exert these effects or what are their precise behavioral significance. Maturing adult sea lamprey, locate suitable spawning habitat using a pheromone released by stream-dwelling larvae. Behavioral studies (Vrieze and Sorensen, 2001) showed that water form streams with larvae is more attractive to adults than water from stream without larvae, that adding larval odor to stream water increases its attractiveness and that individual larvae create a large "active space" (the volume of water activated by pheromone) of about 1000 *l* in an hour. During upstream migration, lamprey undergoes final maturation (spermiation and ovulation), lose behavioral responsiveness to the larval pheromone and develop behavioral responsiveness to the odor of mature conspecifics of the opposite sex (Teeter, 1980; Bjerselius et al., 2000). The 3-Keto-petromyzonal-sulphate (3K-PS; 7α, 12 α, 24-trihydroxy-3-one-5 α-cholan-24-sulphate) appears to be potent (10^{-12} M EOG threshold) component of the pheromone released by spermiated male sea lamprey (Li et al., 2002; Yun et al., 2003). Sorensen's laboratory tested the ingredients of the larvae extract to see which one was the best lure. They found that the most active compound in the mix is a scent closely related to squalamine, a compound so far only found in sharks, where it is thought to act as an antibiotic. This approach could also be effective with other fish, according to Sorensen, since many species use pheromones to navigate even in tiny concentrations.

Artificial chemoattractants

The work of Prof. Peter Sorensen, University of Minnesota, USA worked on lampreys in use of artificial pheromone in attracting fish (Nature News 2005). Advances in isolating lamprey, carp and goldfish specific pheromone cues have led to the possibility of employing sensory attractants (pheromones). The male carp sex pheromone cue was found to be species-specific, sex-specific and potent. Androstenedione (a potent olfactory stimulant of carp and a known component of the goldfish sex pheromone) explains about half of the extract's behavioural activity in the laboratory. Synthetic prostaglandin implants can induce pheromone release in female carp for up to a week and field trials have shown attraction of male carp into the vicinity of the cage in which PGF2α-implanted female carp was held. Electrophysiological experiments, proposed that amino acids dissolved in the home stream water were possible home stream odor chemo-attractants for salmon (Shoji et al., 2000). Evidence shows that amino acids may play an important role as chemical signals in olfactory and gustatory response in fish and the correlation between stimulatory effectiveness and molecular structure of amino acids has been suggested (Suzuki and Tucker, 1971). A synergistic effect was observed for mixture of some amino-acid in the gustatory of several fish species (Hidaka et al., 1976; Yoshii et al., 1979) and, in addition, electro-physiological responses to some amino-acids are enhanced by the presence of another amino-acid in cross-adaption experiments (Marui and Kiyohara, 1987).

For *T. ilisha*, studies on anatomy, orientation and nature of lateral line cells to its environment are not available and hence, how lateral line contributes to migration of the fish is not known. The homing of mature adults and return of young ones and adults has any involvement of mechanoreceptors with different neuromast orientations for detection of direction of water current is not known. The free neuromast and other canal organs may also serve different purposes as chemoreceptor. Chemoreception, in association with mechanoreception, may together direct the fish for migration. Karlsen and Sand (1987) observed that mechanoreceptive behavior of fish greatly diminished when lateral line function was inhibited by $CoCl_2$ application. This $CoCl_2$ treatment results in the release of Co ions, disrupting ionic transport and preventing signal transduction in the lateral lines. Further, trials utilizing either a gentamicin dip or external scraping of the lateral lines, to disrupt canal and superficial receptor respectively, demonstrated that these behaviors were dependent specifically on mechanoreceptor located within the canal of the lateral line (Coombs et al., 2001). Similar to salmon, it is possible that migration of *T. ilisha* might be regulated by olfactory imprinting when lateral line systems are poorly developed as a part of sensory mechanisms; this could be more reliable option for homing *T. ilisha*. But olfactory biology of *T. ilisha* has not been attempted till date and hence its role in migration is not known. Response of hormones against 'riverine odorants' could confirm imprinting function in *T. ilisha*. Comparative details of expression of olfactory imprinting gene between migratory and landlocked populations of *T. ilisha* (Ukai stock for example) may confirm chemoattractive nature of the fish. As in the case of *T. ilisha*, both the sexes migrate between natal and feeding grounds and hence possibility of pheromone regulation of reproductive partners may not give sufficient explanation. But amino acids, especially gustatory stimuli, might be a clue. As its food mostly includes planktonic items (Ashan et al., 2012), nitrogen rich planktonic foods (e.g. some cyanophyceae) might contribute to its outward migration for feeding. The striking part is that, like many other marine fish (Bell, 1998), *T. ilisha* also accumulates high concentration of oils, ahead of migration, which are subsequently used to support energy for swimming and gonad development. Are these gustatory events guiding migration though chemoreception to differences in food quality between natal and feeding grounds? For *T.ilisha*, this might provide supporting information to olfactory imprinting. Some of the most recent researches using electrophysiological and molecular methods have shown that salmon have high olfactory sensitivity to some amino acids (Carruth et al., 2002; Yamamoto et al., 2010; Johnstone et al., 2011; Ueda, 2011). Occurrence of a similar trophic guided migration might be possible for Hilsa.

ARTIFICIAL PROPAGATION

In view of the great national and international interest as well as enormous commercial and social importance of hilsa in the light of drastic decline in its natural resources, there is need for development of alternate production strategies through breeding, seed production and grow out technology for the species. Though several attempts for artificial spawning of the fish have been made since 1908 (Wilson, 1909; Raj, 1917; Southwell and Prashad, 1918; Kulkarni, 1950), the efforts succeeded only in the late 1970's (Malhotra et al., 1969; Malhotra et al., 1970; Mathur et al., 1974). However for some reason these efforts, although not completely successful, were not followed up for developing into a successful venture. The information thus generated are enumerated below. *T. ilisha* is gonochoristic, unlike other *Tenualosa* spp., as there is no evidence of sex change (Blaber et al., 2001), although there is one report of hermaphroditism in the species by Chacko and

Artificial fecundation of hilsa by stripping. Source : ICAR-CIFRI

Krishnamurthy (1949). Artificial propagation of hilsa has been attempted by a number of workers for several years, with varying levels of success. Perhaps first success of artificially fertilizing the eggs was by Wilson (1909) using specimens collected from Coleroon river, a tributary of Cauvery River. Later, the Madras Fisheries Department fabricated a jar hatchery (Mc Donald Jar) for mass scale production of hilsa hatchlings for ranching in the South Indian rivers during 1912; that was not successful. Attempts made by Raj (1917) was also not successful. The attempts made by Southwell and Prashad (1918) at Monghyr along the Ganga river could fertilize the eggs, but the eggs did not hatch. Kulkarni (1950) and Dixitulu and Chacko (1962) could strip and bred the fish but was not successful in rearing the hatchlings beyond 2-3 days. Jones and Menon (1951), Motwani et al. (1957), Karamchandani (1961), could record the development of fertilized eggs and larval development, based on the natural collection from Ganga, Hooghly and Narmada rivers. Malhotra et al. (1969, 1970 and 1979) and Mathur et al. (1974) could breed the fish successfully by dry stripping of brooders collected from Ganga river. De (1986); De and Sen (1986) and Sen et al. (1990) could breed the fish successfully by dry stripping of brooders collected from Ganga river and rear the hatchlings up two years in freshwater ponds. De (1986); De and Sen (1986); De and Sinha (1987); Sen et al. (1990) could breed fish by wet stripping along the lower stretch of Ganga river at Farakka and rear the hatchlings in a freshwater ponds at Rahara fish farm, West Bengal, for a period of four months. The results obtained in experiments conducted by Sen et al. (1990) is given in Table 31. The favorable time for fertilization was afternoon or evening (De, 1986; De and Sinha, 1987; Sen et al., 1990). Fertilization, hatching experiments conducted by Malhotra et al. (1970) in *hapa* fixed in river water

Table 31. Results of experiments on artificial fecundation and rearing

Expt.	Date of stripping	Time of Stripping (hrs)	Size of male (g)	Size of female (g)	Fertilization (%)	No. of hatchlings	Stocking in natural pond	Size at the end of culture
1	16 Oct 1984	1510	425-475	600	40	4000	3 days old	80 mm
2	17 Oct 1984	1530	700	1300	45	21000	2 days old	at the
3	24 Oct 1984	1650	350-400	600	50	20000	2 days old	end of
4	31 Oct 1984	1530	700	1600	30	4000	2 days old	4 months

Source : Sen et al. (1990)

and in nursery ponds, varied from 5 to 80 % in riverine environment while it was 15 to 30 % in nursery ponds. Malhotra and Shah (1979) reported that pH, Ca and Fe had vital role in hatching success at ranges of 7.4 to 7.6, 62.5 to 133.0 ppm and 0.6 to 2.2 ppm, respectively. Although better hatching percentage was recorded when developing eggs were incubated under laboratory conditions with provision for regulated flow of water (De, 1986; De and Sinha, 1987; Sen et al., 1990). Rahman, et al. (2017) conducted on-board breeding trial of *T. ilisha* and tested larval rearing in Bangladesh waters and reported that although it was not possible to be succeeded completely in artificial breeding of the fish, the experience of on board breeding trial in the major breeding ground of river Meghna will give the necessary insight for future works.

Hatchery

The success in artificial breeding of hilsa, through stripping of wild collected brooders and rearing the hatchlings, resulted in thinking of having a hatchery for the fish for mass scale production of seeds. Although the hatcheries designed worked to some extent, commercial success was not achieved. The attempts made include a make shift hatchery set up at Bharbhut in Gujarat in the 1980s (CIFRI, 1989-90). Breeding was attempted through stripping of brooders of 1.0 to 1.3 kg collected from river Narmada resulting in 58-80% fertilization and 35-45% hatching which led to production of 7.5 lakh spawn. They were reared in nursery ponds at Umarwada and Ukai Fish Farms, Gujarat. Survival of spawn was very low. The design of the hatchery used at Gujarat is shown in Fig. 33. The hatchery trials conducted

Fig. 33. Hilsa hatchery tested by ICAR-CIFRI, at Gujarat (A. hatchery cluster, B. close view of a hatchery unit, C. inside view of modified hatchery, D. metallic frame of grid hatchery, E. close view of plastic hatching chamber and F. inner view of plastic hatching chamber). Source: ICAR-CIFRI Annual report 1989-90

at Farakka, West Bengal (CIFRI, 1989-90) consisted of a plastic pool of 75 cm depth and 90 cm diameter having water outlet on top and round markin cloth happa inside and a perforated plastic basket (60 cm height and 40 cm diameter) lined on the inner side with 1.2 mm mesh cloth. A water circulating device was fitted in the bottom. About 50000 fertilized eggs could be incubated in the hatchery until hatching. Hatching percentage obtained was 90-92 in the hatchery. During 2000, the Central Inland Fisheries Research Institute developed designs for a circular grid model hatchery for hilsa. The model hilsa hatchery consisted of overhead tank, incubation unit and hatchling collection unit, as shown in (Fig. 34). River water stored in overhead tanks (5000 l capacity), placed about 4 m above the ground, provided water for the hatchery operation.

was vertically held in the jar midway. A net cloth, fitted in a circular frame, having a diameter similar to inner diameter of the jar, was placed horizontally inside the jar below the opening of the outlet. The distal end of the inlet pipe was provided with uniform perforations all around, which reached near the bottom of the jar in such a way that the outflow of water starts from the bottom of the jar in the form of a sprinkle. The top of the jar had a spout, which served as the outlet for excess water. The hatchling unit consisted of fiberglass tank provided with an outlet pipe, a framed nylon organdy cloth happa having very fine mesh and an overhead shower. The tank was used for collection of hatchlings. The outlet pipes of the hatching jars were placed in a way that the discharge of water along with hatchlings was collected in the happa fixed in the fiber-glass tank. An overhead shower was

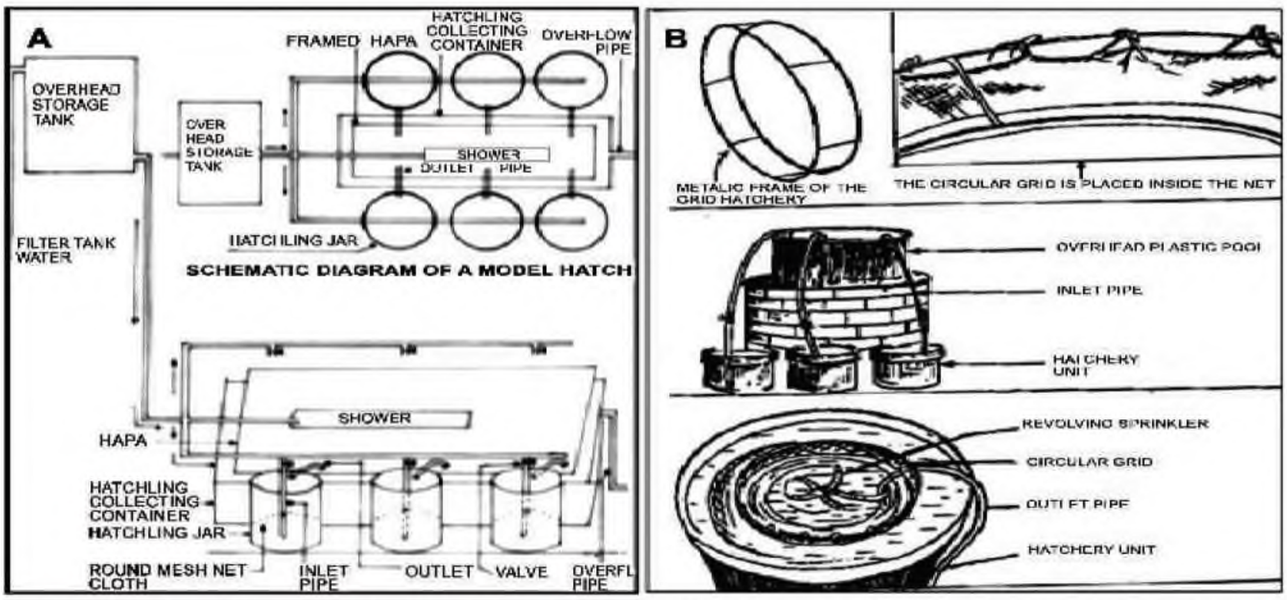


Fig. 34. Sketch of model hatchery design (A) and sketch of circular grid hatchery (B). Source: De, D. K. (personal communication)

The incubation unit consisted of a battery of circular glass jars having a capacity of 5 l each. The inner diameter of the jar was 30 cm. Each jar received water from the storage tank through metallic (aluminum) or polyethylene pipe, which

provided for augmenting oxygen and maintaining feeble circulation. The fertilized eggs were released directly in to the hatching pool at a rate of 6000-8000 nos. Considering the soft demersal nature of the eggs, slow rate of water flow was maintained, which was sufficient for keeping eggs in buoyant condition. After hatching, the larvae moved vertically in the water column. Vertical movement of hatchlings, coupled with similar movement of water, facilitated their escape through the horizontally placed net cloth. Only unfertilized eggs and broken egg shells were left inside the hatching jars below the net cloth, which were removed manually after the entire operation of hatching was over. The hatchlings were kept in the hatchling containers/units for 2-3 days before stocking in nursery ponds. In addition to the model hilsa hatchery, a portable circular grid hatchery was tested for incubating and hatching fertilized eggs (Fig. 34).

This consisted of a plastic pool of 1.2 m diameter and 0.9 m height with provision for outlet of water below 0.15 m of its top, a revolving sprinkler and a circular grid. The grid was made of two rings of thick wire, each of 0.6 m diameters. These are attached together by vertical bars. A mesh cloth of 1.5 mm mesh size at the bottom and 2 mm at the side was fastened on to the frame. The sprinkler with its inlet pipe from the overhead plastic pool was placed at the bottom of the plastic pool. The plastic pool was filled with the water until it came out through its outlet. The grid was then placed at the centre of the plastic pool six inches below the surface of water by means of two supports, which held the grid in position through hooks. The capacity of each unit of the hatchery complex was 1.5 lakh water hardened eggs. The fertilized and water hardened eggs were gently placed in the grid with a feeble circular water current maintained through a revolving sprinkler. Within 18-21 hours at 28 °C (27 to 29 °C) the hatchlings came out from the egg shells and found their way to plastic pool through the side wall of the grid. The grid, along with the unfertilized eggs and egg shells were removed. The overall hatching was 50 to 85%.

Transport

The success in culture of hilsa largely depends on reliable transport methods for brooders, larvae and fingerlings for stocking in ponds. First attempt was on transportation of spawn by Malhotra et al. (1969) and concluded that yolked larvae of *T. ilisha* can be transported successfully in oxygen packing. A series of experiments on the transport of fertilized eggs and hatchlings, using both open and closed containers were followed. In the closed system, the fry were packed in polythene bag (16 l capacity) placed in a tin carrier with 4-5 litre of sieved clear river water under pressurized oxygen. The density ranged from 5-10/l. The duration of transport ranged between 2 and 6 hours. In the closed system of transport under pressurized oxygen, high rate of mortality was reported. Almost 100% mortality was recorded when anesthetics such as Chloral hydrate at the rate of 25, 50, 75 and 100 mg/1 concentration was used while transporting. Fry could be transported in open fiberglass tank, at a density of 800 nos./200 l of water, for 6 hour with 60-75% survival (De et al., 1987). Sen et al. (1990) transported 49000, one day old (3.62-3.75 mm) and two day old (4.00-4.12 mm) hatchlings from Farakka to Rahara Research Centre, West Bengal; a distance of about 300 km, within a period of 12-16 hours. The hatchlings were transported in open containers at a density of 1000 nos./l in clean settled river water. They recorded 5-10% mortality during transportation. They transported 22000 hatchlings of one and two days old to CIFRI, Barrackpore from Farakka, a distance of about 290 km and reported 20% mortality during transportation. De et al. (1987) conducted a series of experiments on the transport of hilsa fry using both open and closed systems. Hilsa fry were caught by shore seine

'Chat berjal' during October-December in 1982 and 1983 from the freshwater stretch of the Hooghly estuary at Dhatrigram at a distance of 280 km from the river mouth. The maximum availability of hilsa fry (20-60 mm) recorded was 8-10 kg per net. Live fry were collected in enamel trays from the net before transferring them to plastic pools and transported by jeep to CIFRI Barrackpore, a distance of about 130 km. Heavy mortality took place during acclimatization. In the open system, the conditioned fry (25-70 mm) were transported in open plastic pools (300 l, having 200 l water) and fiber glass tanks (4.5' x 3' x 3' having 200 l water) for a duration of six hours without artificial aeration or oxygenation. Sieved river water was used in all the experiments and the stocking density of fry varied from 0.375-2 nos/l or 1fry /0.5-2.66 l (in plastic pool) and 1-4 nos./l or 1 fry/0.25-1.0 l (in FRP tank). Highest percentage of mortality (72 %) was observed in case of one fry in 0.8/l of water (plastic pool). Lowest percentage of mortality (25 %) was observed in the case of one fry per 0.25/l of water (fibre glass tank, 200 l). Water temperature was 23-27°C. In the closed system, under pressurized oxygen in polythene bag (16 l; with 4-5 l of water), high rate of mortality (72-100%) of fry (20-65mm) was reported with at a stocking density of 5-10 nos./l at temperatures of 23-25 and 32-33°C. They concluded that better survival rate of Hilsa fry can be obtained in open containers without any artificial aeration or oxygenation than in closed system. They could not draw a definite conclusion for mass mortality in closed system. However, they pointed out that sufficient DO and low water temperature may perhaps be factors for better survival.

Culture

Several workers, during the 1980s, have attempted culture of hilsa in freshwater ponds using fry collected from river and also using captive bred fry. The results of these studies are enumerated in Table 32. High rate of mortality and stunted growth of hatchlings or fry were

Table 32. Growth of hilsa in different culture conditions as reported by different authors

Culture system	Source	Initial length/ weigh	Culture duration	Growth	Author (s)
Cemented cistern	Natural collection	50-80 mm	9 months	Av. 40 mm	Pillay (1958)
Freshwater pond	Artificial breeding	2.5-6.0 mm	36 days 69 days 1 year 2 year 2 year 4 months	41.0 mm 53.0 mm 155.0mm 320.5 mm 345.0 mm	Mathur et al. (1974); Malhotra and Shah (1979)
Freshwater pond	Natural collection (Hooghly)	25-60 mm	1 year 2 year 2 year 8 months	l80 mm/125g 310 mm/ 300g 350mm/ 425g	Bhanot and De (1984)
Freshwater pond	Natural collection	100-400 g	1 year 6 months	300-800 g	Sharma (1984)
Vallab- sagar reservoir	Artificial breeding	20-25 mm	1 year 5 months 1 year 7 months	500 g 600 g	Panicker et al. (1982)
Cemented pond	Artificial breeding	3.5-4.5 mm	47 days	40 mm	De and Sinha (1987)
Freshwater pond	Artificial breeding	3.6-4.1 mm	4 months	80mm	Sen et al. (1990)

reported under all types of rearing. Lack of knowledge on ideal food and water quality needs were attributed to the mortality. The other possibility suggested was change of habitat, particularly of fry/ fingerlings when they were to start migrating to saltwater. Hatchlings were provided with finely powdered supplementary feed prepared with rice bran and ground nut oil cake at the rate of 5-l0 g (1:1 ratio), once in a day, besides the natural food (plankton) present in the nursery pond. However it is not clear whether the larvae accepted the supplementary feed provided. Nevertheless, some of the results showed that growth of hilsa in rearing experiments were not much different from the natural growth (De, 1986; De and Datta, 1990a). The results obtained by various workers indicated that there is possibility for successful farming of the fish if suitable environmental conditions and food are taken care of. Sahoo et al. (2016) list out historical attempts on artificial breeding, larval rearing and culture of hilsa, and commented on the research gaps that need to be addressed by future aquaculture development programs for hilsa in South Asia.

Table 33. Monthly length-weight increment in the experimental pond culture of hilsa (1988-89) in Bangladesh.

Month	Pond -1		Pond-2	
	Av. length (cm)	Av. weight (g)	Av. length (cm)	Av. weight (g)
March, 1988	5.31	1.25	5.31	1.25
April	8.82	7.09	8.19	7.28
May	11.25	23.25	12.59	24.89
June	14.39	42.50	15.55	45.61
July	16.65	58.70	18.46	63.72
August	17.85	73.08	20.21	94.40
September	18.56	86.38	22.84	116.82
October	19.39	97.00	24.71	164.54
November	20.05	100.11	25.50	190.75
December	20.97	111.13	26.01	230.62
January, 1989	21.86	114.17	27.92	254.50
February	22.56	119.28	28.91	267.33
Av. increment	1.44	9.83	1.97	22.17

Source: Rahman, et al. (2012)

In all culture trials of hilsa, mortality usually started after 30-35 days of rearing. Few advanced fry could be reared for three months and still fewer survived for four months in some of the experiments. In the culture attempts by De and Sinha (1987), the average sizes attended by the stock were 30, 58, 65, 70 and 80 mm at the end of 27, 50, 75, 90 and 120 days of rearing, respectively. While the same hatchlings stocked in well prepared cement cisterns, with supplementary feeding, showed a growth of up to 40 mm in 47 days of rearing. Thereafter, total mortality was reported. With a view to propagate hilsa in reservoir, 500 fry of 20-25 mm size, obtained through artificial fecundation, were released in Vallabhasagar in October, 1979. After 17 months of stocking two hilsa specimens weighing about 500 g each and 2 months later one more gravid female hilsa weighing 600 g could be recovered at the time of fishing by commercial fishermen (Panicker et al., 1982). Similar attempt on hilsa farming was made by West Bengal State Fisheries Research Station, in collaboration with progressive farmers at Jaipur. Hilsa weighing 100-400 g were collected from the natural source and stocked in well prepared pond. Out of 190 hilsa released, only 80 specimens survived. After one and half years of culture period, the stock had grown to 300-800 g in weight (Sharma, 1984). Culture of hilsa has also been attempted in Bangladesh during the 1980s without much success (Table 33). With respect to taste, texture, flavor and fat content, both the cultured hilsa and riverine hilsa were very close to each other. Some of the female specimens from the pond were sacrificed to check their gonadal development and observed that after one year they attained only 1st stage of gonad maturity, while river specimen had crossed 2nd stage. Though several attempts have been made to adapt hilsa to captive conditions, none of them reached commercial success.

Cage based culture systems

Cage farming of fish has been popular to bring additional production of high value fish (Fredriksson et al., 1999). Cage culture of fish was initiated in Norway during 1950s and developed into a high tech industry, particularly for salmon farming. The cage farming industry, particularly in northern Europe, North America, Chile and Japan, expanded dramatically during the 1980s and 1990s and attracted interests of large number of multinational companies seeking to diversify into a new and growing market (Slaattelid, 1990). Cage culture of marine fish has grown rapidly over the last decade in Asia, Europe and Australia, utilizing inshore or offshore areas (Benetti et al., 1998). Cage aquaculture has emerged as a promising venture and offers the farmer a chance for optimal utilization of the existing water resources which in most cases have only limited use for other purposes. The earliest record of cage culture practices dates back to the late 1800 in Southeast Asia, particularly in the freshwater lakes and river systems of Kampuchea. Marine fish farming in cages traces its beginning to the 1950s in Japan where fish farming research at the Fisheries Laboratory of the Kinki University led to the commercial culture of yellow tail *Seriola quinqueradiata* and developed into a significant industry as early as 1960. Since the 1970s, Thailand has developed cage culture techniques for two important marine finfish: the sea bream (*Pagrus major*) and grouper (*Epinephelus* spp.). Large scale cage farming of groupers were established in Malaysia in 1980. Korea started cage culture in the late 1970s and by the end of 1980s, cage culture of the olive flounder (*Paralichthys olivacens*) and black rockfish (*Sebastes schlegeli*) was established, and developed into a successful aquaculture industry in the 1990s. In Europe, cage culture of rainbow trout (*Oncorhynchus mykiss*) in freshwater began in the late 1950s and in Norway, Atlantic salmon (*Salmo salar*) followed by the 1960s. More than 40% of its rainbow trout comes from freshwater cages. Salmonid culture is currently dominated by production from Norway, Scotland and Chile. Less than 1% of world's aquaculture production comes from cages. Cage culture is growing at a very impressive rate (Huguenin, 1997). The fish family wise cage aquaculture production is dominated by Salmonidae (66%) followed by Sparidae (7%), Carangidae (7%), Pangasiidae (6%), Cichlidae (4%), Moronidae (3%), Scorpaenidae (1%), Cyprinidae (1%) and Centropomidae (1%) (Tacon and Halwart, 2007). There are 80 species of finfishes currently cultured in cages all over the world. Of these, *Salmo salar* accounted for half (51%). Production and growth of cage cultured rainbow trout (*Salmo gairdneri*) as reported by various authors are given in Table 34.

Cage aquaculture of southern bluefin tuna in Australia is based on fattening fish in offshore cages. Juveniles weighing 5 to 10 kg are caught offshore with purse seines and stocked in holding cage. Fish are counted and weighed before being transferred to the transport (towable) cages, where they remain for several days while being towed to the grow out cages located off Port Lincoln. Growth rate of southern bluefin tuna in

Table 34. Production and growth data from cage cultured rainbow trout (*Salmo gairdneri*)

Source	Stocking size (g)	Harvest size (g)	Culture period (days)	Average weight gain/fish/ day (g)	Conversion rate	Survival (%)	Production (kg m^{-3})	Daily weight gain (%)
Buck et al. (1972)	94	185	74	1.2	4.0	65.5	81.0	1.27
Collins (1972)	85	340	115	2.2	1.5	96.1	30.3	2.58
Hahn (1974)	4	75	126	0.56	3.2	59.6	8.4	14.0
Kilambi et al. (1977)	150	297	138	1.1	2.6	99.0	65.3	0.73
Roell (1983)	35	89 - 102	47	1.16-1.44	1.0-1.8	96.6-98.3	1.9-2.3	3.31-4.11
Tatum (1973)	94	338	120	2.0	3.9	77.2	64.7	2.12
Whitaker and Martin (1974)	8-14	153- 200	122- 130	1.19-1.43	1.5	54.0		10.21-14.87

cages is estimated at 2 to 5% of body weight per day. The grow out period ranged from three to ten months (Benetti, 2000). In nursery and grow-out offshore cages in Taiwan, 100-600 g Cobia were cultured for 1-1.5 years when they reached 6-10 kg for the domestic market. Currently, around 80% of marine cages in Taiwan are devoted to culture of Cobia (Liao et al., 2004) in circular cages of 10-16 m diameter and 7-9 m in depth.

No attempt has been made so far on possibilities of culture of hilsa *in situ* in river/ offshore in floating cages. There might be a possibility, as the fish will get most of the desired parameters while in cage. *In-situ* farming of hilsa in floating cages in different salinity regimes might provide the fish with optimum natural conditions of water quality favouring high growth and survival. Cages installed off shore in higher salinities might help faster growth and maturation of the fish, which might not be possible in pond-based freshwater systems. Hence attempt of culture of hilsa in cages hold high potential as well as equal amount of challenges with regard to design, stability and management of cages in flowing rivers and turbulent estuaries and also with regard to the very survival of hilsa in cages.

CONSERVATION

The lucrative commercial fisheries of the fish along the major estuaries, more particularly along the Hooghly estuary, have drastically declined due to recruitment failure and indiscriminate exploitation of adults and juveniles, inviting management interventions for sustaining the fisheries. In India, hilsa fisheries management is largely a state subject rather than a national responsibility. The status reports on hilsa indicated increasing fishing efforts and declining catch. Legislated seasonal fishing closures and size at capture guidelines exist in States, like West Bengal and Gujarat. There is some degree of regulation in effect with regard to smaller size groups. Recently the Government of West Bengal, based on the recommendations provided by ICAR-CIFRI, has issued gazette notification on 9th April 2013, to implement restriction and regulation of catching of hilsa to facilitate their migration, breeding and growth. The salient features of this notification are as following.

- Any kind of monofilament gill nets having mesh size below 90 mm has been prohibited in the marine sector.
- Any kind of monofilament gill nets having mesh size below 90 mm and other nets having mesh size below 40 mm have been banned in the inland sector.
- Capture of hilsa below 23 cm has been prohibited during February to April every year in estuarine area and bay mouth.
- No one is permitted to sell, transport or posses hilsa having length below 23 cm.
- Bottom trawling in shallow continental shelf (12 nautical miles) has been banned.
- Capture of hilsa of any size, during the five days prior and post to full moon during 15th September to 24th October, every year, has been completely banned for facilitating breeding.
- All types of fish catch are banned in the hilsa Sanctuaries (Between Nishchintpur to Diamond Harbour, Between Hooghly Ghat to Kalna and Between Lalbagh to Farakka) during June to August and October to December.
- Hilsa fishing is prohibited within 5 sq. m. of the Farakka barrage round the year to protect brooders.

As hilsa is distributed in several countries, joint efforts by hilsa fishing countries might work better for conservation of the species. BOBLME (Bay of Bengal Large Marine Ecosystem, an intergovernmental initiative) targeting the resource management in the Bay of Bengal has also been working on development of a regional fishery assessment plan for hilsa and provide stock status advice in Bangladesh, India and Myanmar. IUCN Trans-boundary policy dialogue also recommended joint action by Bangladesh and India for sustainable hilsa fisheries management (www.iucn.org).

KNOWLEDGE GAPS

The information available on hilsa shows it as a much studied fish, nevertheless there are still critical gaps in knowledge on the species with regard to its biology, migration, physiology, reproduction and fisheries. From the above review, some of the knowledge gaps identified are as following.

- Apart from the knowledge that hilsa is an anadromous fish, migrates to freshwater riverine areas for breeding and young ones move to marine areas for growth and maturation and its need for low salinities for breeding, the habitat requirement in various stages of life cycle is unclear. Whether there is a completely freshwater or marine stock is yet to be conclusively answered.
- Though there are a number of studies on the environmental requirements of hilsa, very little is known about the factors that induce spawning and migration.
- With regard to migration, how many times the fish migrate to freshwater and back in its life span or the freshwater migration is linked to only breeding or not are not well understood.
- A number of studies have been carried out on the age and growth and size at age of the fish without any conclusive estimate as different authors have reported different estimates for this and

wherever available are all pertaining studies conducted way back.

- Although a good amount of information is available on the biology, with regard to food and feeding, breeding and migration, there are still grey areas, especially with regard to materity spawning behavior and breeding grounds.
- The food and feeding habits and food items have been reported, however whether the fish has any food preference, whether the gut items that are reported are digested by the fish are unclear. Occurrence of large quantity of sand particles in its stomach has any role or they are accidental entries are to be examined.
- Reproductive biology, with regard to maturity stages, morphological characters of gonads, ova diameter progression, size at first maturity, fecundity, breeding seasons and periodicity have been studied in the past. However, recent studies indicated perceptible change in these parameters, which need to be established for meaningful utilization of these parameters for conservation and management of the species.
- Two to three spawning grounds have been reported along the river Hooghly, whether these are permanent breeding grounds or not are to be established for decision making on investment for protecting these grounds.
- The population dynamics and stock structure of the fish has been studied during the 1970s and 1980s; since then the changes that might have occurred in its population and natural stocks are not known, which are essential for its resource management for conservation and sustainable fisheries.
- The current level of exploitation, sustainable yield limits, size to be caught for optimum yield and strength of the spawning stocks need to be established for suggesting sustainable fishing guidelines.
- Although there are information on the catch and landing of the fish, the corresponding fishing effort is not recorded for use in reliable estimation of sustainable yield levels.
- Genetic characterization and stock delineation of hilsa has been attempted, however the question on whether there is a single stock or there are multiple stocks of the fish in Indian waters is still to be conclusively established and little is known on its genome-wide variations and divergence.
- Biochemical changes in the fish during migration has been investigated, however the information available are patchy and sporadic in nature, hence of less use in understanding the fish.
- The osmoregulatory and reproductive physiology and the concurrent morpho-histological adaptations are still to be clearly established.
- Artificial breeding of hilsa has been attempted through stripping, however rearing the fry up to advanced fingerling stage encountered large-scale mortality; reasons are not known.

- Water quality, feed and nutrition requirements of larval, juvenile and adult stages are unknown.
- The rearing of spawn has not been successful and requires further investigations to achieve this.
- Knowledge on feed requirement of larval stages, young ones and adults are still not known.
- Rearing in freshwater lakes and ponds up to table size has been attempted, however the growth rates and survival achieved were poor, apparently due to lack of knowledge of water quality requirement and feed requirement.
- Rearing in freshwater up to table size has also been attempted however with partial success; the information available is restricted to length and weight increment of the fish, no information on the production and survival obtained from these experiments.
- The growth performance in brackish water and seawater in captivity and also rearing *in situ* have not been attempted.
- Apart from the gut contents and their seasonal changes, the nutrient requirement of the fish is unknown.
- The sensory mechanisms of the fish, their functioning and how it navigates to freshwater and back or is there a homing mechanism are unknown.
- Olfactory or gustatory biology of the fish has not been studied.

PROJECT APPROACH

As the natural resources of *T. ilisha* are drastically declining there is a compelling need for conservation and rehabilitation of its declining fishery and equally important are domestication through captive breeding and culture of the species. The approach of the project 'Stock characterization, captive breeding, seed production and culture of hilsa (*Tenualosa ilisha*)' funded by the ICAR-National Agricultural Science Fund, New Delhi, under the broad strategic priority area of water quality and productivity (culture of high value and endangered marine species in inland freshwater) is to generate information on the natural stock, biology, population dynamics, genetics for helping its natural resource management decision, while generation of knowledge on its habitat preference, physiological and reproductive mechanisms and development of captive breeding and rearing and feed would help its domestication and aquaculture. The objectives of the project are as following.

- Assessment of natural stock of hilsa and their habitat preference, biology and biochemical composition in different ecosystems (Hooghly, Narmada and Ukai reservoir)
- Develop knowledge base on genome-wide variation and population structure of hilsa to support breeding programmes for aquaculture and natural stock management
- Evaluation of osmoregulatory and endocrine changes of hilsa in relation to ionic homeostasis and gonadal maturation.

- Development and standardization of captive breeding, seed production and culture systems for hilsa.
- Development of feeds for hilsa and augmentation of its homing by developing chemo-attractants.

To address the objectives seven specialized institutions, as following, with the Central Inland Fisheries Research Institute as lead center, are involved in a consortium mode.

- Central Institute of Fisheries Education, Kolkata Center, 32-GN Block, Sector-V, Salt Lake City, Kolkata-700 091, West Bengal.
- Kakdwip Research Centre, Central Institute of Brackish water Aquaculture, Kakdwip, West Bengal-743 347.
- Regional Research Center of Central Institute of Freshwater Aquaculture, A-5 (Phase-III), Santalpara, Kalyani-741 235, West Bengal.
- Visakhapatnam Regional Centre of Central Marine Fisheries Research Institute, Pandurangapuram, Visakhapatnam – 530 003, Andhra Pradesh.
- National Bureau of Fish Genetic Resources, Canal Ring Road, P.O. Dilkusha, Lucknow- 226 002, Uttar Pradesh.
- Visva-Bharati University, Santiniketan - 731235, West Bengal.

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