KRISHNA ESTUARY – ECOLOGY AND FISHERIES

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Barrackpore, Kolkata - 700120, West Bengal

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FOREWORD

Estuaries are highly dynamic ecosystems, supporting diverse habitats with distinctly diverse biotic communities. In recent times, however, these systems have been subjected to various stress factors, primarily arising out of river valley modifications, which in turn have created imbalances at various levels of utility functions, including the fisheries. Loss of ecological services, including the fishery and biodiversity, has become the hallmark of the estuarine ecosystems in the country. The estuaries are the extremely exploited ecosystems, being intimately associated with the mankind, throughout the globe. It is imperative, therefore, to develop suitable protocols for the effective management of fisheries besides the conservation of biodiversity. To ensure this, generation of time series data is essential so that location specific effective management protocols based on scientific principles are in place.

Krishna estuary, Andhra Pradesh, in the east coast of India, is one of the finest estuarine systems of the country, supporting the livelihood concerns of thousands of traditional fishers. In recent years the system has been degraded due to increased anthropogenic interferences, like the construction of Prakasam barrage near Vijaywada. The resultant impact has been dismal discharge of freshwater into the system. The Krishna has almost converted into a tide-fed estuary, affecting the ecological integrity and biodiversity, adversely.

In the backdrop of such a development and dearth of authentic information on the ecology and fisheries of Krishna estuary, especially during the changed ecological regimes, the Central Inland Fisheries Research Institute, Barrackpore, undertook a detailed investigation to generate baseline information on various facets of ecology besides understanding the present state-of-art on fishery and biodiversity, during 2005-07. I am sure the information generated during the course of the present investigation and the recommendations suggested in the text will be highly beneficial to the concerned agencies in the effective management of its fishery and conservation of precious biodiversity.

I wish to put on record my sincere thank to the officials of the department of fisheries, Govt. of Andhra Pradesh for their cooperation during the course of the present investigation. I also appreciate the good work done by the CIFRI team for generating valuable information from Krishna estuary, which was hitherto highly scanty.

Place: Barrackpore — **K. K. Vass**
Date: November, 2008 — **Director**

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INTRODUCTION

The peninsular India is highly rich in estuarine resources with a number of major and minor estuaries, as well as estuarine waters, contributing to the inland fish catch sizably. Krishna estuary (latitude 16°02′ N; longitude 80° 53′ E), Andhra Pradesh with an area of 320 km^2 is an important mesotidal estuary with a tidal amplitude of 2-3 m. Nadimeru, Golumuttapaya and Hamsaladevipaya are the three tributaries debouch into it, making the system highly rich in biodiversity and fishery. In recent times, however, Krishna estuary has been a victim of anthropogenic interferences, especially in terms of its hydrology, which has been altered significantly, due to the construction of dams and barrages across river Krishna, upstream. The freshwater inflow into the system has thus become a critical factor during the larger part of the year, barring the monsoon.

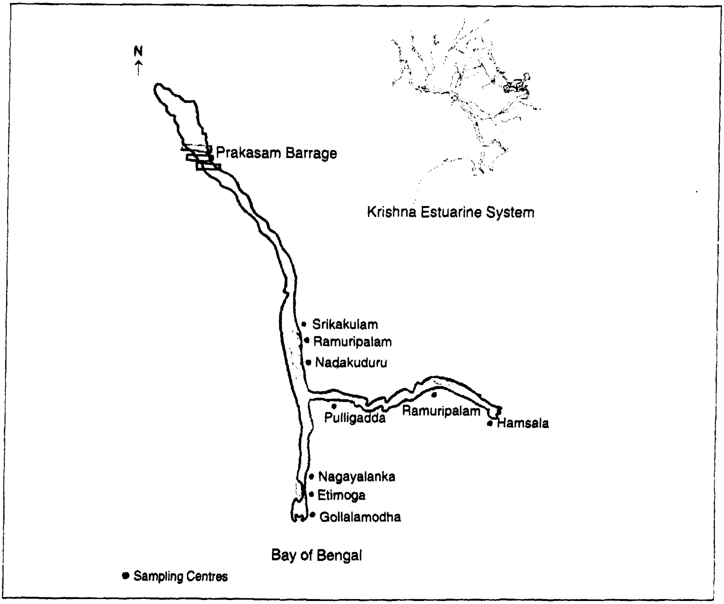
The estuaries, being highly complex ecosystems due to varying salinity gradients, from freshwater to marine environment, portray diverse habitats with varied biotic communities, including the fish fauna. It is prudent therefore, to develop thorough understanding on the habitat variables and biodiversity for effective management and sustainable utilization of estuarine fisheries. The Krishna is one of the important estuaries of peninsular India, but scientific information on its ecology and fisheries is scanty (David, 1963; Sarin *et al.* 1985; Zingde, 1989).

Taking a cognizance on the information gap, CIFRI undertook a detailed investigation on its ecology and fishery, covering a stretch of 80 km, between Srikakulam (near Vijaywada) and Hamsala (sea face), over the period 2005 to 2007. The main aim of the present investigation was to understand the status of ecology, biodiversity and fish production potentiality of the estuary in the changed ecological regime for formulating appropriate fisheries management guidelines.

PHYSICAL FEATURE OF THE KRISHNA RIVER ESTUARY

The Krishna is a rain-fed river, originating from 4000-5000 ft high of Western Ghat, south of Poona. Among the human habitations on either bank of Krishna estuary, the city of Vijaywada is located near its delta on the east cost. Over the year, a large number of reservoirs have come into existence across the Krishna river system *viz.* Lakkvalli, Thungabhadra, Koyna and Vanivilassagar. In addition to these, a number of small reservoirs have also been constructed across its minor tributaries like Mutha, Ghata- prabha, Musi and Easi rivers. The Prakasam Barrage constructed across Krishna at Vijayawada has altered the whole gamut of ecology and fisheries of Krishna estuary (Map 1), as the bulk of the impounded water is being diverted for irrigation, allowing a little to support the estuarine habitat, especially during summer. Almost a dry stretch has become the hallmark between the barrage and the estuary during the lean season.

MAP OF RIVER KRISHNA AND ITS FLOW DOWN PRAKASAM BARRAGE SHOWING DIFFERENT SAMPALING CENTRES



ECOLOGY OF KRISHNA ESTUARY

Physico-chemical profile of Krishna Estuary

Depth

The upper estuarine stretch between Srikakulam and Nadakuduru has been found to be a stressed zone due to less availability of freshwater, resulting which 90-95% of the area becomes almost dry after the monsoon. Evidently, the upper estuarine zone indicated negligible fishery, as compared to the lower estuarine region, where water depth was always > 3 m.

Transparency

The Secchi disc transparency, indicated medium to high values throughout the period under study. The gradient zone (Nagayalanka, Pulligada, Ramuripalam) had relatively higher transparency, as compared to freshwater and marine zones, which is contrary to the observations made in Hooghly estuary (Nath, 1998). In Krishna the transparency has been maximum during winter and early summer, while it was minimum during monsoon and post-monsoon months.

Temperature

Air temperature varied between 26.5°C and 38°C, while it was 26°C to 35°C in ambient water. The mean water temperature, from 29.16°C to 31.67°C, indicating prolonged summer in this estuary. Water temperature during 2006-07 (30.02°C) was relatively higher as compared to 2005-06 (27.64°C). Thermal stratification could not be recorded in Krishna estuary, may be due to tidal impact. The thermal regime of Krishna estuary, therefore, appeared to be favourable for the growth and survivability of fish and other aquatic organisms.

Dissolved Oxygen

Dissolved oxygen content ranged from 4.8 to 8.0 mgl^{-1} with the mean values varying between 6.16 and 7.34mgl^{-1}. Relatively low D.O. was recorded during 2006-07 (6.57 mgl^{-1}), as compared to that of 2005-06 (7.0 mgl^{-1}), coinciding with relatively high water temperature. The freshwater and gradient zones indicated relatively higher values of dissolved oxygen, compared to the lower estuary.

pH

The water reaction was slightly alkaline with pH values ranging between 7.4 and 8.5 while the mean values ranged between 7.92 and 8.18. The pH values indicated an increasing trend during the period of investigation, but no zonal variation of pH could be recorded. Comparatively, however, the freshwater zone had moderately higher pH values.

Total alkalinity

Concentration of total alkalinity ranged between 92 and 206 mgl^{-1} with the mean values from 125.3 to 158.0 mgl^{-1}. Relatively higher values were recorded during 2006-2007 (152.7 mgl^{-1}), as compared to 05-06 (131.4 mgl^{-1}). The upper freshwater region indicated higher values, as compared to the estuarine zone. In general the total alkalinity values indicated a decreasing trend with the increase in salinity, corroborating the findings of Ray, 1981.

Free CO_2

Free CO_2 contents were generally low (Nil –5.0 mgl^{-1}), indicating the absence of any pollution load, either industrial or municipal. Free CO_2 in small concentration is considered to be favourable for adequate photosynthetic activities through the autotrophs, phytoplankton and other algae.

Sp. Conductivity

The Sp. Conductivity values indicated significant variations in different zones. In upper estuary (Srikakulam, Nadakuduru) the values ranged between 0.19 and 2.19 milli mhos/cm, while at Hamsala (near sea mouth) it varied from 19.41 and 42.1 milli mhos/cm, indicating a direct relationship with salinity.

Total dissolved salt

The TDS content (0.124-27.37 gl^{-1}) followed a similar trend, as observed in case of sp. conductivity. Relatively, higher values were recorded during 2006-2007, as compared to those during 05-06. In general sp. conductivity and TDS values were maximum during summer and minimum during monsoon months.

Salinity

Salinity fluctuated widely (0.14-35.6 gl^{-1}), depending on season and the zones. Minimum salinity was recorded at the upper estuary (Srikakulam, Nadakuduru). Ramuripalam was situated at gradient zone (4.50 gl^{-1}) while high salinity was recorded at Hamsala (Av.30.83 gl^{-1}) followed by Gollalamodha (18.4-35.6 gl^{-1}), Etimoga (10.32-35.23 gl^{-1}), Palakayatippa (2.1-34.86 gl^{-1}) and Nagayalanka (4.36-28.0 gl^{-1}). During summer the upper zone of the estuary was dry due to negligible discharge from the river resulting in higher salinity in the estuary. During monsoon salinity was reduced by freshwater discharge (0.14-19.89 gl^{-1}) and the mean salinity was near 10.0gl^{-1}. Salinity in Krishna estuary was lower during 2006-07 compared to that recorded in previous year presumably due to good monsoon.

Nitrate

Nitrate content ranged from 0.012 to 0.45 mgl^{-1} and the mean contents ranged between 0.065 and 0.21 mgl^{-1}. Maximum content was recorded at the upper estuary (freshwater zone) while minimum content was observed at the marine zone (lower estuary), which indicated that the nutrient was allochthonous. Similar trend has also been observed by Staver *et al.* (1996) in Choptank river estuary and by Nath (1998) in Hooghly estuary.

Phosphate

Phosphate content ranged from 0.02 to 0.36 mgl^{-1} with mean values ranging between 0.06 and 0.3 mgl^{-1}. The upper and lower estuaries generally indicated relatively higher values, which might be due to input of additional nutrients from allochthonous sources. Staver *et al.* (1996) and Nath (1998) also observed similar trend in Hooghly estuary.

Silicate

The values of silicate recorded varying from 0.7 to 13.3 mgl^{-1} with a mean range of 1.76 to 10.0 mgl^{-1}, being maximum at the upper estuary while the minimum at the lower estuary. During summer nitrate, phosphate and silicate contents were invariably low, but increased to the maximum during monsoon and post monsoon, coinciding with the decline in salinity concentration. Sarma et al. (1993) and Nath (1998) also observed an inverse correlation between the silicate and salinity. Rabalais *et al.* (1996) observed that the decrease in salinity is a consequence of upstream phosphorus addition that stimulates freshwater diatom production and an eventual burial in freshwater sediments of silica in diatom remains, thus reducing the supply of riverine silicate to coastal waters.

Sulphate

Sulphate content ranged between 5.0 and 123.3 mgl^{-1}, while its mean values varied from 18.72 to 106.5 mgl^{-1}. Minimum content was recorded towards the upper estuary, while it was maximum at the lower estuary. A similar trend has also been recorded in case of Hooghly estuary (Nath, 1998).

Calcium and magnesium

Calcium and Magnesium are the two important nutrients essential for the enhancement of aquatic productivity. Moderately good values of Ca (19.64) and Mg (14.38 mgl^{-1}) were recorded towards the upper estuary (Srikakulam) while their maximum values were at the lower estuary, at Hamsala (Ca, 475.6 and Mg, 1282.6 mgl^{-1}). It was interesting to observe that the calcium content was higher than magnesium towards the freshwater zone, but at the gradient and marine zones magnesium content was higher than that of calcium. Similar trends have also been recorded in Hooghly estuary (Nath, 1998).

Hardness

Hardness content ranged between 60 and 8000 mgl^{-1} with the mean contents varied from 109 to 6533.6 mgl^{-1}. Maximum sulphate, hardness, calcium and sp. conductivity were recorded at Hamsala (lower estuary) while they were the minimum at Srikakulam (upper estuary). Sulphate, hardness, calcium, magnesium and sp.conductivity were maximum during summer and minimum during monsoon season.

Physico chemical characteristics of water of Krishna estuary are shown in Table 1 and 2.

Soil characteristics of Krishna estuary

Physico-chemical features

The soil characteristics of Krishna estuary are depicted in Table 3 and 4 while the mean values have been shown in Table 4. Soil samples were collected from nine centers during summer, monsoon, post-monsoon and winter. The salient results are as under:

pH

The soil reaction was near neutral to slightly alkaline, with pH ranging from 6.32 to 8.57. The mean pH ranged between 7.45 and 7.69. In general, soil pH was lower during summer and higher during monsoon and post monsoon, indicating ingress of alkaline materials from the catchments during monsoon.

Sp. conductivity

The sp. conductivity values varied widely, from 0.081 to 17.80 millimhos/cm while the mean values varied between 0.27 and 6.58 millimhos/cm. The minimum conductivity was recorded at the upper estuary (Srikakulam and Nadakuduru) while Hamsala (6.58), Gollalamodha (5.12), Palakayatippa (5.210) and Etimoga (4.6) in lower estuary had the higher values, relatively. In general, the centers having higher conductivity tend to be more productive. The seasonal variations of sp. conductivity values indicated relatively higher values during summer while they were the minimum during monsoon, which coincided with the observation (Nath, 1998) in Hooghly estuary.

Organic carbon

Organic carbon content ranged between 0.09 and 0.69% with the mean content varying from 0.25 to 0.42%. The organic carbon content was moderately low due to poor freshwater discharge from the catchments areas as well as from the river due to damming of rivers. The mangrove forest, which is known for the enrichment of organic matter in estuaries, has also been insignificant in Krishna Estuary. Perusal of data indicates low organic carbon during summer, which, however, showed an increasing trend from monsoon onwards, indicating relatively higher ingress of organic carbon along with the monsoon waters.

Available nitrogen

Available nitrogen content ranged between 5.0 and 17.36 mg/100g soil with the mean content varying between 8.3 and 12.32 mg/100g. The status of available nitrogen content indicated that the estuary was deficient in nitrogen, as such poor in productivity, but free from any pollution load.

Total nitrogen

Total nitrogen content ranged between 0.008 and 0.0535% with the mean value varied from 0.02 to 0.04%. The total nitrogen content also indicated nitrogen deficient estuarine environment thereby poor in productivity.

Available phosphate

Available phosphate content ranged from 0.06 to 6.24 mg/100g and the mean content varied from 1.54 to 4.02-mg/100g soil. In general the lower estuarine zone appeared to have higher content than the freshwater zone. Similar trend was also recorded in Hooghly estuary (Nath, 1998).

Free calcium carbonate

Free calcium carbonate content ranged from 3.0 to 10% and the mean content varied from 6.46 to 7.83%. No significant seasonal or zonal variations were recorded in the estuary for Calcium carbonate. Thus, minimum calcium carbonate was recorded during summer and maximum during monsoon during 2006-07 while just opposite trend was found during 2005-06 presumably due to flooding of the catchments.

Texture of the soil

Clay

The bottom sediment of Krishna estuary indicated poor clay content ranging from trace to 8.0% with a mean range of 0.18 to 3.0%.

Silt

Silt content ranged from Nil to 62.54% with a mean range of 1.67 to 30.6%, being the maximum at Palakayatippa (Av. 46.6%) followed by Gollalamodha (30.6%) and Etimoga (Av. 19.55%). The other centres had lower contents (1.67-7.3%).

Sand

Sand content varied widely both seasonally and center-wise. Barring Gollalamodha and Palakayatippa, all other centers had very high sand content. The soil texture was loamy sand in general.

Factors	% Composition
Clay	Traces-8.0 (mean 0.18-3.0)
Silt	Nil-62.54 (mean 1.67-46.5)
Fine Sand	Nil-91.43 (mean 33.4-63.5)
Course sand	1.23-98.0 (mean 15.0-57.4)

In general the physico-chemical characteristics in particular and ecology as a whole of Krishna estuary appeared to depend largely on the availability of freshwater from the river and the catchments. Available data indicates that the estuary is a victim of erratic freshwater supply between the period 1989 and 2000 it received on an average 735.22 TMC (Av.735.229 TMC) of freshwater, supporting reasonably good productivity. Later on, however, it declined an all time low at 5.9-69.5 TMC (Av. 26.59 TMC) during 2001-2004, affecting the estuarine system adversely. Again during 2005 and 2006 it increased to 1213.66 and 966 TMC, respectively, improving the ecology and productivity of the estuary. Evidently, freshwater discharge in Krishna estuary is a critical factor towards the production and productivity of the system.

Primary production

Gross primary production ($mgC/m^2/hr$) ranged between 25 and 187.5 with a mean range of 49 to 126.3. In general lower production was recorded at the upper estuary (Nadakuduru and Srikakulam), while it was maximum at the lower estuary (Hamsala and Palakayatippa).

Net primary production ($mgC/m^2/hr$) ranged between 15 and 156.2 with a mean range of 25 to 82.6. Minimum net production was recorded at Freshwater Zone (Nadakuduru) while it was maximum at Nagayalanka in lower estuary.

Community respiration ranged between 12.5 and 131.25 $mgC/m^2/hr$ with a mean range of 28.0 to 78.95 $mgC/m^2/hr$. The respiration values were minimum at the gradient zone, followed by upper estuary. The lower estuarine stretch, however, indicated relatively higher values.

Perusal of primary productivity data revealed less productive upper freshwater stretch while the lower estuary was highly productive.

The Net primary production was maximum during post-monsoon while gross production was high during monsoon and post monsoon, indicating the role of nutrients received through allochthonous sources being drained during monsoon months.

BIOTIC PRODUCTION

Plankton profile

As seen from the overall average density, plankton ranged from 249 to 503 ul^{-1} being maximum during premonsoon and minimum in the monsoon period. Phytoplankton (69.3%) was dominant over zooplankton (30.7%). The qualitative texture of phytoplankton spectrum revealed the presence of 93 species with greater dominance of Bacillariophyceae (68.23-90.08%) followed by Dinophyceae (18.30-22.63%), Myxophyceae (3.56-6.25%), Chlorophyceae (2.89-3.11%) and Xanthophyceae (1.30-1.82%). The members of Euglenoids were also recorded at times, especially towards the upper stretch of the estuary (>1%). A total of 23 species of zooplankton were identified belonging to Cyclops (45.00-62.12%), Protozoans (16.15-23.00%), Rotifers (6.23-8.15%) and Cladocerans (3.98-5.64%). The Krishna estuary indicated insignificant variations among the biotic texture between sampling stations and seasons, barring the monsoon, which indicated homogenous distribution of communities being single ecological entity. Seasonal variation in plankton of Hooghly estuary (2005-07) is given in table 5.

Macro-benthos

Quantitative and qualitative assessment of macro-benthos of the Krishna estuary was done. As seen from the overall average (1157 nos/m^2), the density of macro-benthos in Krishna estuary was low. The concentration was more in the gradient and upper zones (67%) than the marine zone (33%). Benthic population did not show any marked seasonal variation. The abundance fluctuated in a narrow range 1091-1217 nos/m^2 during pre-monsoon, monsoon and post-monsoon seasons. Diversity did not show any marked variation. Molluscs (87.1%) were abundant represented by Gastropods (69.2%) with the forms like *Thiara, Indoplanorbis, Lymnaea, Cerithidea, Pila, Telescopium, Bellamya, Gangetia, Pugilina, Columbella, Pythia, Ellobium, Littorina Neritina, Nassarius, Clithon, Cerithidea, Gyraulus etc.* and Bivalves (17.9%) like *Parreysia, Corbicula, Lamellidens Scapharca, Donex, Modiolus, Barnia, Meretrix, Timoclea, Paphia etc.* Higher concentration of molluscs during monsoons coincided with their recruitment phase. The occurrence of insects (7.2%) and annelids (5.7%) was poor.

The mean abundance of macro-benthos (nos/m^2) in all the three seasons at different centers of the estuary was statistically compared using analysis of variance technique. But no significant difference was observed between mean abundance of macro-benthos in pre-monsoon, monsoon and post-monsoon ($p>0.05$). Seasonal abundance of macro benthos is presented in Table 6

Periphyton

The periphyton diversity of Krishna estuary indicated the greater dominance of diatoms followed by blue-greens. The overall sequence of periphyton population in Krishna could be depicted as: *diatoms* (Bacillariophyceae) ▶ *blue-greens* (Cyanophyceae) ▶ *green algae* (Chlorophyceae) ▶ *protozoa* (animalcules) ▶ *Yellow algae* (Xanthophyceae) ▶ *Dinoflagellates*. The density of periphyton ranged from 1250 nos/cm^2 to 4500 nos/cm^2 with relatively higher concentration towards the lower estuarine stretch. The distribution of periphytic organisms, belonging to various groups, indicated specific preference of water quality, especially the salinity concentration, for greater proliferation, as the abundance of cyanophyceae and chlorophyceae was relatively higher in the freshwater stretch whereas diatoms were the dominant contributors in the saline stretch. A total of 72 species of periphyton were recorded, among which a number of organisms recorded in the plankton assemblage of the system, also. The dominant periphytic organisms were as under: *Oscillatoria, Oedogonium and Nitzschia.*

Groups	Dominant species
Algae	
Bacillariophyceae	***Psuedo-nitzschia serrata serrata, Gomphonema parvulum, G. constrictum, G. intricum, Achnanthes sp., B. sinensis, Chaetoceros dadayi, C. affinis, c. mitra, Rhizosolenia acicularis, Synedra nitzschioides, Thalassiosira delicatula, Guinardia sp.***
Chlorophyceae	***Oedogonium tenue, Tetraspora lacustris, Golenkinia radia, Schroedaria ancora, Pediastrum clatheratum, Coelastrum reticulatum, Treubaria crassipina, Tetraedron enorme, Oocystis silitaria, Chodatella chodati, Ankistrodesmus falcatus, Scenedesmus spp.***
Cyanophyceae	***Rhabdoderma lineare, Merispopedia elegans, Microcystis aeruginosa, Gloeocapsa sp., Anabaena spirodis, Gloeotrichia echinulatus, Oscillatoria limosa, O. princeps, Lyngbya limentica***
Xanthophyceae	***Ophicytium sp.***
Dinophyceae	***Peridinium spp., Ceratium sp., Prophacus spp.***
Protozoa	***Difflugia pyriformis, Centropyxis aculeate, Chilodonella sp., Tintinnid sp.***

FISH AND FISHERIES

FISH FAUNA

The information on fish and fisheries of the Krishna estuary is scanty. During the present investigations, 47 fish species belonging to 30 families and 40 genera were recorded from the Krishna estuary. The fish fauna was predominated by the estuarine and marine species. The occurrence of freshwater forms was negligible. Besides, prawns (*L. styliferus, M. monoceros, M. brevicornis, P. indicus, P. monodon*) and crab (*Scylla serrata*) were also recorded from the estuary. The list of fish fauna of Krishna estuary is given below:

Family	Species
Muraenesocidae	*Muraenesox bagio*
Clupeidae	*Hilsa ilisha* *Hilsa kelee*
	Anodontostoma *chacunda*
	Ilisha melastoma
Chanidae	*Chanos chanos*
Cyprinidae	*Puntius spp*
Bagridae	*Mystus vittatus*
Ariidae	*Arius caelatus*
	Arius platystomus
Hemiramphidae	*Hyporhamphus limbatus*
Centropomidae	*Lates calcarifer*
Ambassidae	*Ambassis gymnocephalus*
	Chanda nama
Teraponidae	*Terapon jarbua*
Sillaginidae	*Sillago sihama*
Carangidae	*Caranx ignobilis*
	Chorinemus tallo
	Scomber microlepidotus
Leiognathidae	*Leiognathus equulus*
Lutjanidae	*Lutjanus argentimaculatus*
	*Lutjanus quinque*linearis
	Lutjanus johni

Family	Species
Gerreidae	*Gerres filamentosus*
	Gerreomorpha setifer
Haemulidae	*Pomadasys argenteus*
	Pomadasys commersonnii
Sparidae	*Rhabdosargus sarba*
Mullidae	*Upeneus sulphureus*
Drepanidae	*Drepane punctatus*
Scatophagidae	*Scatophagus argus*
Cichlidae	*Etroplus suratensis*
Mugilidae	*Mugil cephalus*
	Valamugil cunnesius
	Rhinomugil corsula
	Liza parsia
	Liza spp
Polynemidae	*Polydactylus indicus*
Eleotrididae	*Butis butis*
Trichiuridae	*Trichiurus savala*
Bothidae	*Pseudorhombus arsius*
Scombridae	*Rastrelliger kanagurta*
Sciaenidae	*Dendrophysa russelli*
	Johnius carouna
Engraulididae	*Thryssa kammalensoides*
Sphyraneidae	*Sphyraena obtusata*

FISHERIES

Regimental river water discharge from the up-stream barrage across Krishna estuary has significant impact on its salinity r[illegible] thereby its fisheries. The estuary tends to become hypersaline in nature during the larger part of the year, barring a brief monsoon period, due to more of tidal ingress and less of freshwater. The resultant impact has been disappearance or rare presence of oligohaline as well as the freshwater species *viz.* carps, catfishes, murrels, feather-backs, *etc*. During the period under investigation the mullets like *Mugil cephalus*, *Liza parsia* and *Liza* *spp*, followed by clupeids, perches, sciaenids, catfishes, penaeid prawns and crabs contributed to the commercial fish catch.

Major fishing activities observed restricted towards the lower part of the estuary, Nagayalanka being the main fish-landing centre. The period between November and April has been the peak fishing season in Krishna estuary while fish landing during May to mid of July could be considered as the lean season. The period between mid-July and mid-October has been the fishing holiday being the 'closed season'.

Data on annual fish catch (Source: State Fisheries Department and Fishermen Cooperative Societies), indicated a total fish production of 540 t (= 90 kg/ha) during the year 2004-05. The fishing effort and the fish catch for the year 2005-06 were estimated based on the data generated under the project, especially during the pre- and post-monsoon campaigns. The total fishing effort and CPUE were estimated at 36,000 boat-tide; 13.6 kg/boat/tide in post-monsoon and 3750 boat-tide; 1.74 kg/boat/tide in pre-monsoon, respectively. The total annual catch for the year 2005-06 was estimated at 496.1 t (= 83 kg/ha). Of which, the bulk of the catch (489.6 t) was recorded during post-monsoon while the contribution of pre-monsoon catch, in the total landing, was 6.5 t only.

The State Fisheries Department issues licenses @ Rs.75/-per year for motorized boat and Rs.8-9/-per country boat per year. The country boats were found restricted mainly to the estuarine fishing while the motorized boats found to be operated in estuary as well as in sea fishing. During 2004-05, about 884 licenses were issued, 771 (80.4%) for the country boats and 173 (19.6%) for the motorized boats. Gillnets (*Gidasavala/Eduvala/Teluvala*), dragnets (*Laguduvala*) and cast-nets (*Esuruvala*)) were the main fishing gears operated in the estuary for the commercial fishery. Hooks & lines (*Galam*), Crab-nets (*Peetavala*) and Stake-nets (*Gidasavala*) were also used, restricted to certain pockets only.

RECRUITMENT OF FISH SEED

Observations on the recruitment of fish seeds indicated that the breeding of commercially important species takes place during the monsoon season, only. The recruitment of spawn was relatively high in the upper zone (75-85 nos/net/hr) as compared to the lower zone (3-8 nos/net/hr) of the estuarine system. During the post-monsoon season the intensity of recruitment declines significantly in upper (8-19 nos/net/hr) and lower (09 nos/net/hr) estuaries. The overall abundance of mullet seeds, both during pre- and post-monsoon was estimated to be 28.3% while the remaining 71.7% was contributed by miscellaneous groups of fish and prawns.

BIOLOGY OF COMMERCIALLY IMPORTANT FISH SPECIES

LENGTH-WEIGHT RELATIONSHIP

Length-weight relationships of two commercially important mullets of the estuary were worked out as shown below:

Mugil cephalus

$W = 0.00002\ L^{2.8998}$

or

$\log W = -4.6990 + 2.8998 \log L \quad (r = 0.9830)$

Where, W = weight (g) and L = length (mm) of fish

'b' value of *M. cephalus* was significantly lower ($P < 0.01$) than '3' indicating allometric pattern of growth

Liza parsia

$W = 0.0000005\ L^{3.5663}$

or

$\log W = -6.3010 + 3.5663 \log L \quad (r = 0.9645)$

'b' value of *L. parsia* was significantly higher ($P < 0.01$) than '3' also indicated allometric growth pattern

SALIENT FINDINGS

- The seasonal variation of ecology, biodiversity and production potential of Krishna estuary revealed an alarming impact of river flow.
- Upper estuary being very shallow and narrow, cannot sustain fish growth, fish breeding or migration on commercial scale.
- Sandy bottom sediment not congenial for nutrient retention or exchange, accordingly the nutrient status in the sediment indicated poor values
- The river valley modifications like Upper-Krishna Projects in Maharashtra, Karnataka and Andhra Pradesh has been found to be the main reason for dwindling freshwater discharge in Krishna estuary downstream of Prakasam Barrage.

- The seawater incursion has been found to be high, especially during high tides, covering > 90% of the tidal stretch.
- Presently, the estuary is largely tide-fed, in absence of adequate freshwater inflow with a tendency of becoming polyhaline (av. salinity >18 ppt).
- The controlled freshwater efflux besides drying up of one-third of estuarine length, towards the upper end, particularly during non-flood seasons, has increased the salinity amplitude to a considerable extent (20-35 ppt).
- Low run-off from the catchments, coupled with poor river drainage has led to inadequate nutrient supply, low proliferation of biotic communities and sub-normal productivity.
- The Krishna estuarine complex, one of the important coastal fisheries resources in east coast, is emerging example of freshwater water deficit system, affecting the production functions and biodiversity adversely.
- During the major part of the year the salinity amplitude has been shifted towards a hyperhaline condition, leading to colossal loss of estuarine biodiversity, including the fish fauna.
- The mullet fishery, however, remained unchanged, rather showing an increasing trend in terms of the annual fish production (about 500 t/annum).

BROAD RECOMMENDATIONS

- Restoration of minimum freshwater flow in the system from the Prakasam Barrage, especially during lean seasons to protect the estuarine characteristics thereby its fisheries and biodiversity
- The ecology and productivity of Krishna estuary may be improved by discharging at least 1300-1500 TMC of freshwater from Prakasam Barrage every year on regular monthly instalments.
- Reduction in fishing efforts by reducing the number of boats to sustainable level with complete restriction on the operation of motorized boats to protect the interest of traditional fishers.
- Making the upper estuarine zone as the protected area, especially during monsoon, for safe and healthy recruitment of fish and prawn species.

- Complete ban on the operation of small meshed disco-nets for the conservation of fish and prawn juveniles to ensure smooth recruitment and sustainable fishery.
- Conserving the recruitment and growth of mullets, the prime fish species of commercial importance, through responsible and rational fishing practices.

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Table 1 : Physico-chemical characteristics (Range) of Krishna estuary (April 2005-March 2007)

Parameters	1	2	3	4	5	6	7	8	9
	Gollala modha	Etimoga	Nagaya- lanka	Pulligada	Ramuri- palam	Nada- kuduru	Srika- kulam	Palakaya- tippa	Hamsala
Air Temp. (°C)	24.5-34.5	24.0-34.0	24.6-34.5	24.0-35.0	25.0-36.0	26.5-34.0	25.0-30.0	27.0-34.0	26.0-34.0
Water Temp. (°C)	22.8-32.0	22.5-32.5	22.9-32.0	23.0-34.0	23.8-34.7	25.0-32.0	24.0-35.0	25.8-32.0	25.0-32.0
Transparency (cm)	22.5-50	19.0-70.0	18.5-100.0	18.0-115.0	28.0-108.0	30.0-60.0	22.0-57.0	24.0-72.0	19.0-40.0
D.O. (mgl^{-1})	5.8-6.4	5.8-8.0	5.2-7.28	5.0-7.6	6.48-7.92	7.0-7.88	6.0-7.6	4.8-6.8	5.2-6.72
pH	7.4-8.4	7.6-8.4	7.5-8.4	7.4-8.4	7.5-8.4	7.8-8.5	7.6-8.4	7.5-8.4	7.5-8.4
Sp.conductivity**	18.70-26.85	17.24-26.25	10.11-23.32	4.5-15.23	0.21-11.15	0.25-2.19	0.19-1.97	2.26-28.2	19.41-42.1
TDS g/l	11.54-17.45	11.206-17.06	6.57-15.16	2.925-9.9	0.136-7.25	0.163-1.423	0.124-1.28	1.469-18.33	12.61-27.365
TA (mgl^{-1})	106.0-158.0	102.0-160.0	94.0-182.0	92.0-196	110.0-200.0	116.0-206.0	114.0-206.0	112.0-163.0	112.0-154.0
Free CO_2 (mgl^{-1})	0.4-4.4	3.0-4.2	Nil-4.8	Nil-4.4	Nil-3.2	Nil-4.0	Nil-4.4	Trace-5.0	Nil-4.8
Chlorinity (gl^{-1})	10.2-19.7	5.7-19.5	2.4-15.5	0.5-15.1	0.08-11.0	0.1-1.1	1.06-1.0	1.15-19.3	11.0-19.5
Salinity (gl^{-1})	18.44-35.6	10.32-35.23	4.36-28.0	0.93-27.3	0.17-19.9	0.21-2.02	0.14-1.84	2.105-34.86	19.885-35.23
NO_3 (mgl^{-1})	0.02-0.164	0.03-0.261	0.024-0.315	0.016-0.357	0.028-0.45	0.084-0.368	0.092-0.37	0.016-0.251	0.012-0.138
Total N (mgl^{-1})	0.248-1.76	0.296-1.49	0.34-1.272	0.098-0.823	0.124-0.915	0.136-1.101	0.144-1.066	0.124-1.609	0.128-1.075
PO_4 (mgl^{-1})	0.031-0.122	0.017-0.150	0.028-0.129	0.029-0.146	0.037-0.365	0.12-0.362	0.12-0.321	0.018-0.142	0.08-0.121
Sulphate (mgl^{-1})	24.66-115.3	80.0-107.66	32.66-102.3	16.0-95.0	5.66-91.66	16.0-43.33	5.0-39.66	70.0-117.7	88.33-123.33
Silicate (mgl^{-1})	2.1-9.322	2.2-9.793	4.7-9.260	5.7-10.0	6.1-12.9	6.7-13.3	8.1-13.3	2.0-9.332	0.7-3.16
Hardness (mgl^{-1})	300.0-7800.0	150.0-7300.0	100.0-6500.0	90.0-5800.0	80.0-4700.0	70.0-300.0	60.0-200.0	200.0-7900.0	5500.0-8000.0
Ca (mgl^{-1})	16.3-593.2	8.016-505.0	7.214-488.9	6.413-376.75	5.61-272.5	4.809-48.09	4.008-48.1	12.825-561.1	360.72-625.25
Mg (mgl^{-1})	589.9-1559.3	31.2-1448.2	19.67-1266.6	17.75-1165.9	4.746-364.5	4.762-67.19	4.75-21.59	40.3-1578.5	944.85-1597.75
Gross.P.P. *	75.0024-171.8	58.33-125.0	75.0-187.5	54.17-138.9	46.0-70.0	25.0-85.0	37.5-93.5	75.0-218.7	41.668-152.8
Net.P.P. *	33.3-156.2	29.17-93.7	25.0-156.25	20.8-93.7	15.5-42.0	15.0-40.0	25.0-62.0	33.3-125.0	20.0-83.3
Resp. *	30.0-75.0	10.0-45.0	25.0-66.7	35.0-112.5	15.0-47.0	12.5-56.0	20.0-75.0	12.5-131.25	25.0-131.25
Depth. (Ft)	17.0-30.0	14.0-32.0	12.0-30.0	6.0-15.0	7.0-20.0	1.0-3.0	1.0-4.0	8.0-20.0	17.0-29.0
Flow rate (ft/min)	20.0-72.0	22.0-75.0	20.0-78.0	20.0-80.0	15.0-85.0	20.0-87.0	18.0-89.0	14.0-45.0	19.0-55.0

Table 2 : Physico-chemical characteristics (Mean) of Krishnna estuary (April 2005-March 2007)

Parameters	1	2	3	4	5	6	7	8	9
	Golla-modha	Etimoga	Nagaya-lanka	Pulligada	Ramuripalam	-Nadaku-duru	Srikaku-lam	Palakaya-tippa	Hamsala
Air temp. (°C)	30.4	30.365	30.08	30.6	30.84	29.75	30.5	30.5	29.915
W.temp. (°C)	28.75	28.95	28.45	29.08	29.37	28.125	29.1	28.915	28.665
Transparency (cm)	32.5	41.5	63.4	76.165	69.19	43.25	37.9	38.5	28.83
D.O (mgl^{-1})	6.875	6.7885	6.68	6.845	7.34	7.27	7	6.16	6.255
pH	8.035	8.1	8.05	8.04	8.05	8.175	8.165	7.915	8.05
Sp.conductivity**	21.125	19.368	15.54	10768	2.94	0.901	1.04	19.35	25.42
TDS g/l.micromhos	13.735	12.5879	10.1073	6.9986	1.90775	0.7685	0.6765	12.5785	16.517
TA (mgl^{-1})	135.665	132.4	138.33	147.165	152.34	158	155	133.835	125.33
Free CO_2 (mgl^{-1})	1.9665	1.7	2.233	1.468	1.7	1.9	1.765	2.7	1.8985
Chlorinity (gl^{-1})	13.8	12.218	8.1	5.6665	2.4785	0.6	0.4605	13.593	17.065
Salinity. (gl^{-1})	24.945	22.05	14.65	10.2622	4.5045	1.112	0.81	24.56	30.829
NO_3 (mgl^{-1})	0.0885	0.1261	0.1185	0.1468	0.1785	0.2045	0.20665	0.1128	0.0646
Total N (mgl^{-1})	0.8548	0.7193	0.7115	0.74115	0.5655	0.5845	0.6283	0.7755	0.616
PO_4 (mgl^{-1})	0.07315	0.2994	0.064	0.0945	0.17985	0.211	0.17755	0.089	0.0876
Sulphate(mgl^{-1})	90.8295	100.05	83.44	68.165	36.6605	23.335	18.72	101.66	106.5
Silicate (mgl^{-1})	4.896	5.1665	6.4295	8.055	9.7115	10.029	9.846	4.2635	1.7598
Hardness (mgl^{-1})	4316.67	3958.33	2683.33	1715	1010.33	167.5	109	4666.67	6533.33
Ca (mgl^{-1})	346.022	283.232	241.687	150.701	77.89	23.246	19.6392	352.17	475.616
Mg (mgl^{-1})	902	780	483.532	321.179	195.74	26.252	14.3766	908.7	1282.63
Gross PP*	98.775	84.54	120.89	105.094	50	49	60	134.72	126.3215
Net PP*	67.699	54.684	82.6255	56	31	25	31	68.92	44.827
Resp.*	46.665	35.75	44.8565	58.88	28	30	32	78.955	63.26
Depth (ft)	19.83	19.248	18	10.5015	11.02	1	1	13.7485	20.835
Flow rate (ft/min)	32.835	35.665	34.4185	28.5	28.665	34.25	40.415	24.33	26.335

*MgC /M^3/hr **millimhos/cm

Table 3 : S characteristics (Range) of Krishna estuary (April 2005 -March 2006)

Parameters	1	2	3	4	5	6	7	8	9
	Gollalamodha	Etimoga	Nagyalanka	Puligada	Ram. palam	Nadakuduru	Srikakulam	Palakayatippa	Hamsala
pH	6.45-8.22	6.32-8.26	6.42-8.46	7.06-8.57	7.02-8.33	7.01-8.24	7.0-8.40	6.31-8.33	6.34-8.49
Sp. conductivity (millimhos/cm)	0.41-16.25	0.49-15.67	0.16-12.36	0.149-4.05	0.132-3.01	0.084-0.22	0.081-1.03	0.47-16.43	1.07-17.80
Total Nitrogen (%)	0.02-0.039	0.019-0.042	0.011-0.029	0.017-0.038	0.028-0.053	0.018-0.051	0.025-0.028	0.015-0.044	0.008-0.039
Available Nitrogen (mg/100g)	8.4-15.68	9.52-14.56	5.0-14.56	7.28-12.88	10.08-13.44	7.84-17.36	6.72-10.08	8.4-12.32	5.04-11.2
Available P_2O_5 (mg/100g)	1.76-5.68	0.62-6.24	0.06-3.6	0.38-5.84	1.0-4.76	1.466-5.94	0.18-3.36	1.82-5.76	0.36-3.04
Organic carbon (%)	0.27-0.69	0.15-0.36	0.12-0.30	0.21-0.42	0.24-0.63	0.24-0.54	0.18-0.33	0.18-0.6	0.09-0.51
Free $CaCO_3$ (%)	4.5-10.0	4.0-10.0	6.0-8.5	3.5-8.0	4.5-9.75	6.5-7.5	5.5-7.75	5.25-8.76	3.0-10.0
Course sand (%)	1.23-74.0	2.0-75	2.94-98.0	19.0-97.0	10.34-98.0	10.0-77.01	30.0-65.86	2.20-70	15.31-48.37
Fine sand (%)	Nil-67.0	Nil-91.43	Nil-79.51	Nil-58.94	Nil-81.43	22.99-75.0	31.46-62.0	Nil-49.88	Nil 84.69
Silt (%)	21.07-48.06	6.33-44.0	Nil-32.62	Nil-3.0	1.0-11.0	Nil-13.0	Nil-7.0	25.0-62.54	Nil-4.0
Clay (%)	0.32-4.0	0.02-6.0	Nil-1.0	Nil-2.0	0.01-2.0	Trace-2	Nil-1.0	0.25-8.0	Nil-2.0
C/N	9.231-16.0714	8.5714-10.714	10.909-11.379	11.0526-12.353	8.57-16.1538	10.589-1333	11.786-12.0	11.471-13.636	11.25-13.769

Table 4: Soil characteristics (Mean) of Krishna estuary (April 2005-March 2007)

Parameters	1	2	3	4	5	6	7	8	9
	Gollala-modha	Etimoga	Nagaya lanka	Pulligada	Ramuripalam	Nadaku duru	Srikakulam	Palakayatippa	Hamsala
pH	7.5	7.45	7.52	7.69	7.615	7.6125	7.47	7.573	7.525
Sp.Conductivity (millimhos/cm)	5.12	4.637	3.266	1.7265	0.8765	0.2655	0.374	5.208	6.58
Total Nitrogen (%)	0.029	0.028	0.02	0.024	0.04	0.0345	0.0265	0.031	0.024
Available N (mg/100g)	11.76	11.67	9.42	8.6335	11.385	12.32	8.305	10.45	7.955
Available P_2O_5 (mg/100g)	3.25	3.7735	1.8935	2.8165	2.785	3.2165	1.54	4.0165	1.97
Organic carbon (%)	0.41	0.31	0.2515	0.2875	0.42	0.42	0.2725	0.36	0.32
Free $CaCO_3$ (%)	6.915	7.835	6.83	6.915	6.835	6.875	6.458	7.375	6.498
Course Sand (%)	15.045	16.98	46.68	57.4075	31.445	41	50.725	15.186	40
Fine Sand (%)	52.995	63.494	46.4855	40.35	60.6565	53.618	46.53	33.414	58.66
Silt (%)	30.597	19.55	6.9	2.43	7.293	3.79	3.155	46.55	1.666
Clay (%)	1.3625	1.56	0.4065	0.51	0.5875	0.666	0.1765	3.0466	0.333

Table 5 : Seasonal variation in plankton of Krishna estuary (2005-07)

Sites	2005-06			2006-07		
	Pre-monsoon	Monsoon	Post-monsoon	Pre-monsoon	Monsoon	Post-monsoon
Gollalamodha	P= 388 Z= 96 T= 484	P= 208 Z= 40 T= 248	P= 436 Z= 88 T= 524	P= 186 Z= 116 T= 302	P= 240 Z= 140 T= 380	P= 421 Z= 88 T= 509
Etimoga	P= 466 Z= 131 T= 597	P= 140 Z= 60 T= 200	P= 200 Z= 80 T= 280	P= 162 Z= 62 T= 224	P= 108 Z= 56 T= 164	P= 152 Z= 92 T= 244
Nagayalanka	P= 292 Z= 192 T= 484	P=198 Z= 48 T= 246	P= 76 Z= 108 T= 184	P= 236 Z= 60 T= 296	P= 480 Z= 198 T= 678	P= 204 Z= 108 T= 312
Puligadda	P= 358 Z= 72 T= 430	P= 232 Z= 32 T= 264	P= 260 Z= 92 T= 352	P= 92T= 168 Z= 76 T= 168	P= 204 Z= 142 T= 346	P= 104 Z= 40 T= 144
Ramuripalam	P= 468 Z= 112 T= 580	P= 192 Z= 80 T= 272	P= 152 Z= 40 T= 192	P= 306 Z= 84 T= 390	P= 204 Z= 188 T= 392	P= 154 Z= 40 T= 194
Nadakuduru	NS	P= 218 Z= 50 T= 268	P= 298 Z= 128 T= 426	NS	P= 176 Z= 56 T= 232	P= 228 Z= 72 T= 300
Srikakulam	NS	P= 228 Z= 88 T= 316	P= 148 Z= 162 T= 310	P= 156 Z= 66 T= 222	P= 204 Z= 294 T= 498	P= 204 Z= 56 T= 260
Palakayatippa	P= 324 Z= 88 T= 412	P= 228 Z= 72 T= 300	P= 94 Z= 220 T= 314	P= 112 Z= 72 T= 184	P= 158 Z= 110 T= 268	P= 249 Z= 152 T= 401
Hamsala	P= 436 Z= 100 T= 536	P= Nil Z= 124 T=124	P= 156 Z= 138 T= 294	P= 140 Z= 96 T= 236	P= 140 Z= 132 T= 272	P= 196 Z= 138 T= 334

P = Phytoplankton; Z = Zooplankton; T = Total; NS = Not sampled

Table 6 : Seasonal abundance of macro-benthos in Krishna estuary during 2005-2007

Centres	Season	Gastropods	Gastropods	Bivalves	Bivalves	Annelids	Annelids	Crab	Crab	Miscellaneous	Miscellaneous
		2005-06	2006-07	2005-06	2006-07	2005-06	2006-07	2005-06	2006-07	2005-06	2006-07
		nos/m	nos/m	nos/m	nos/m	nos/m	nos/m	nos/m	nos/m	nos/m	nos/m
Gollalamoda	S	1043	522	347	87	Nil	43	Nil	Nil	Nil	87
	M	174	5739	43	348	Nil	Nil	Nil	Nil	Nil	Nil
	W	1478	1609	130	522	304	130	Nil	Nil	174	Nil
Etimoga	S	130	478	130	87	Nil	217	Nil	Nil	Nil	Nil
	M	435	1348	87	261	Nil	Nil	Nil	Nil	Nil	Nil
	W	261	1130	87	304	174	130	Nil	Nil	87	87
Nagayalanka	S	782	261	Nil	87	Nil	Nil	Nil	Nil	Nil	130
	M	435	174	87	87	Nil	Nil	Nil	Nil	Nil	Nil
	W	Nil	1087	43	87	87	87	Nil	Nil	174	43
Puligadda	S	9260	391	43	43	Nil	Nil	Nil	Nil	Nil	87
	M	130	1043	87	87	Nil	Nil	Nil	Nil	Nil	Nil
	W	435	391	Nil	87	43	130	Nil	Nil	304	87
Ramuripalam	S	391	304	130	43	Nil	87	Nil	Nil	Nil	130
	M	783	1304	217	435	Nil	Nil	Nil	Nil	Nil	Nil
	W	130	1304	304	174	217	217	Nil	Nil	Nil	43
Nadakuduru	S	Nil	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
	M	391	1522	261	130	Nil	Nil	Nil	Nil	Nil	Nil
	W	1043	1043	43	130	130	261	Nil	Nil	87	87
Srikakulam	S	N.S.	217	N.S.	87	N.S.	Nil	N.S.	Nil	N.S.	130
	M	174	2609	87	652	Nil	Nil	Nil	Nil	Nil	Nil
	W	304	913	Nil	130	Nil	174	Nil	Nil	391	130
Palakayatippa	S	173	348	304	Nil	Nil	130	Nil	87	Nil	87
	M	478	522	174	869	Nil	Nil	Nil	Nil	Nil	Nil
	W	391	478	696	261	130	Nil	Nil	Nil	130	87
Hamsala	S	43	Nil	347	87	Nil	Nil	Nil	Nil	Nil	87
	M	Nil	Nil	522	43	Nil	Nil	Nil	Nil	Nil	174
	W	Nil	Nil	130	217	Nil	Nil	Nil	Nil	87	87

S-Summer M-Monsoon W-Winter

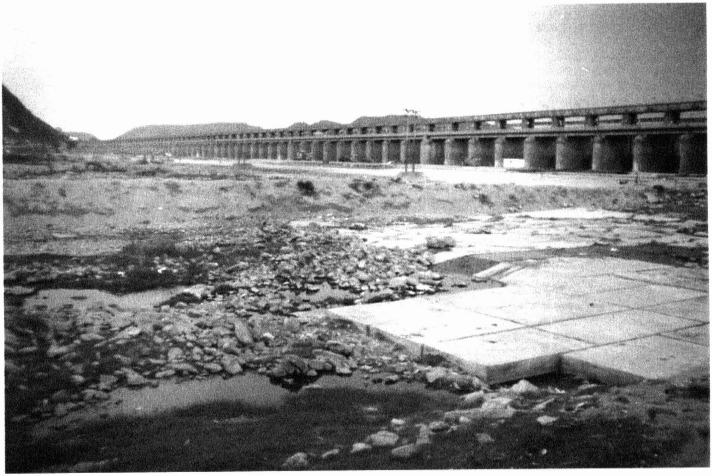

Figure 1: Extreme control of river discharge through Prakasam Barrage during summer

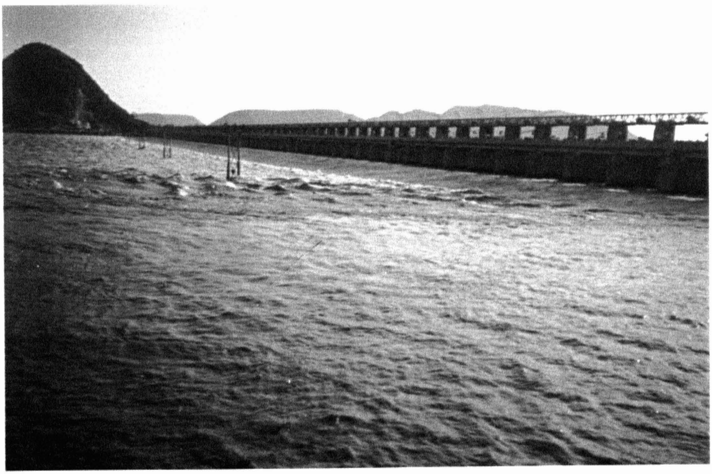

Figure 2: Monsoon release of river discharge during high flood

Figure 3: Natural and cultivated vegetation downstream of Barrage during monsoon season

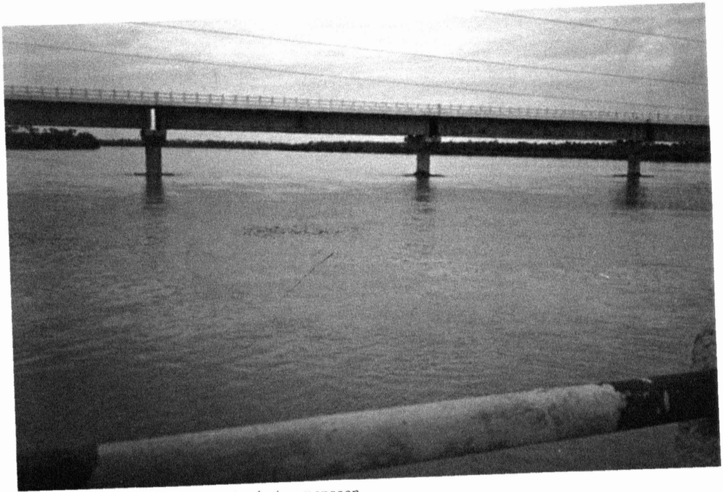

Figure 4: Revived river continuity during monsoon

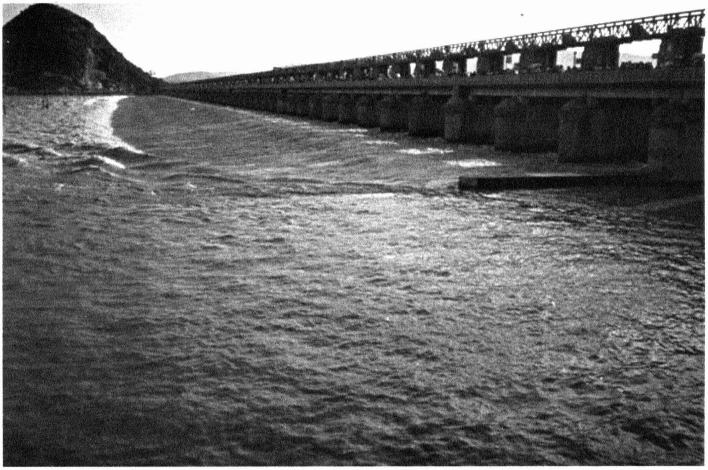

Figure 5: Estuarine habitat extending upstream up to the Barrage

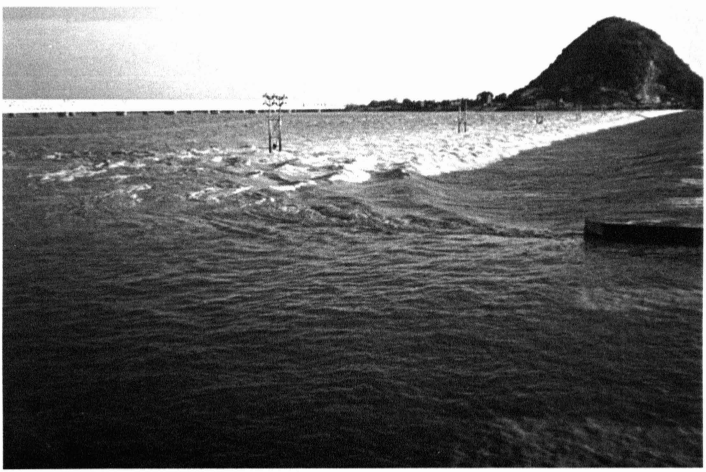

Figure 6: Potential freshwater fishing zone below the Barrage

Figure 7: Sandbars hindering exchange of the estuarine tides and biotic communities

Figure 8: Hydro biological analyses of the estuary

Figure 9: Estuarine submergence in extreme flood condition

Figure 10: Fishers' displacement during extreme flood condition

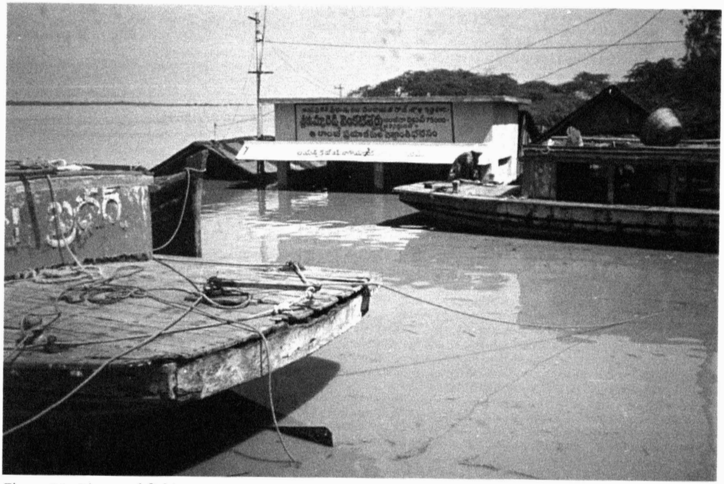

Figure 11: Disrupted fishing activity due to extreme flood

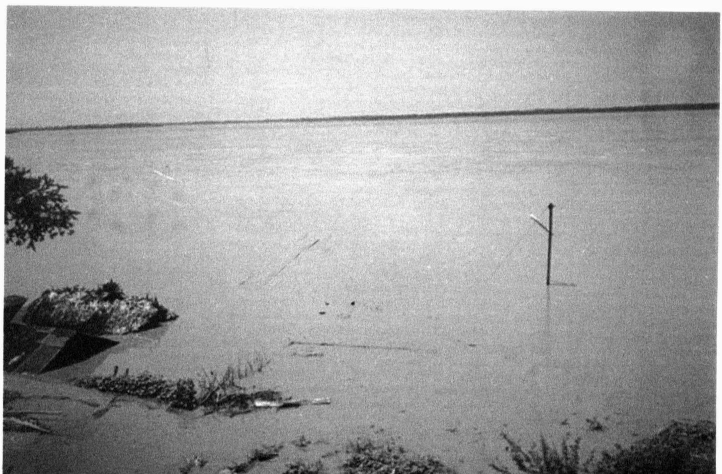

Figure 12: Untoward inundation of estuarine habitats and peripheral habitations

Figure 13: Shore seine fishing in lower estuary

Figure 14: Cast net fishing in shallow margin of the estuary

Figure 15: Productivity studies in the estuary

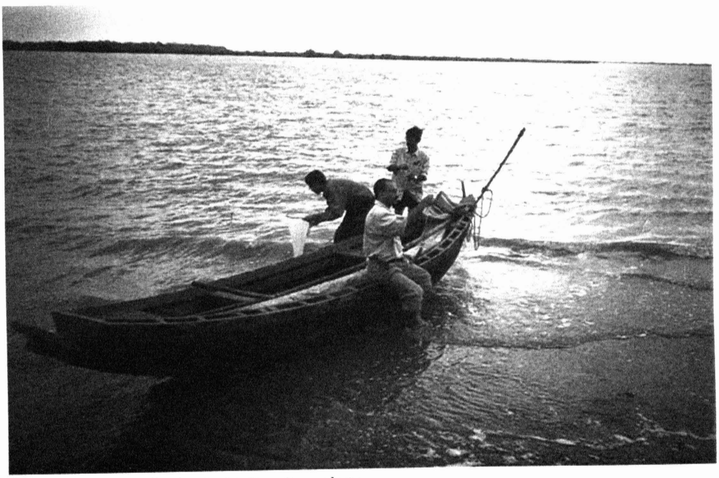

Figure 16: Sample collection for biodiversity analyses

Figure 17: Benthic collection from the sea mouth

Figure 18: Benthic collection from the sea mouth

Figure 19: Sampling for recruitment assessment

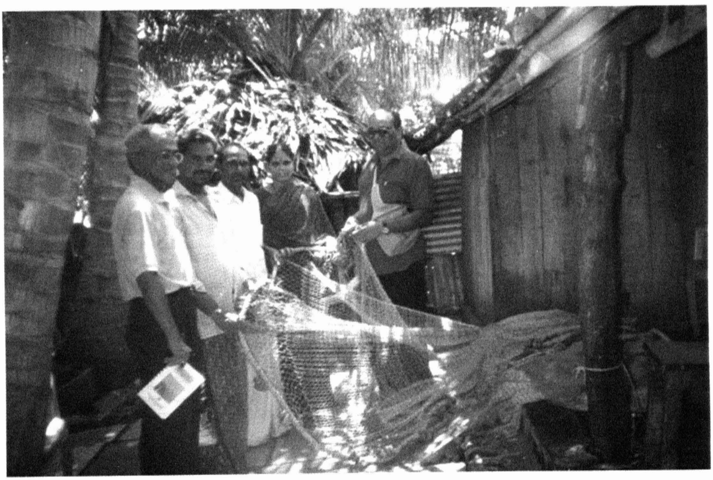

Figure 20: Fishers displaying commonly diploid net

Figure 21: Mullets the major haul from the estuary

Figure 22: Mullet catch for retailing

Figure 23: Single haul of mullets

Figure 24: Mud crabs packed and ready for export