Monitoring and Modelling Lakes and Coastal Environments

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Edited by

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Cover illustrations: Top: The fisherman with his boat and nets casts on the Chilika lake, a coastal lagoon, for making his livelihood in early hours of sunrise. ***Bottom left:*** An artificial inlet mouth of Chilika Lagoon being opened during September, 2000 by Chilika Development Authority in order to have better exchange with the Bay of Bengal and to reverse the process of degradation of the lagoon ecosystem. ***Bottom right:*** A partial view of the Nalabana Wild Life Sanctuary within the Chilika lagoon (approx. area 15.5 km^2) and famous for its intercontinental migratory avifauna. Photographs taken by Mr. Uma Sankar Panda.

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Editorial Board

Preface

Lakes and coastal environment play a vital role in the global ecosystems. Their importance has been recognized in the maintenance of biodiversity, ecology, hydrology and recreation. They provide habitat for wide variety of flora and fauna and help maintain the life cycle of many species. Lakes and coastal environment all over the world are ideal places for human habitation, fisheries, industries, shipping and recreation. Habitat environment of lakes and coastal environment are deteriorating due to their exploitative use and improper management. As rapid development and population growth continue in coastal areas, environmental degradation and over-exploitation will further erode the biodiversity and undermine the productivity of these unique ecosystems.

Lakes and coastal environments are transitional areas between dry terrestrial and permanent aquatic ecosystems and are recognised as highly productive. Their importance in socio-economic frontiers has been increasingly felt. These have been used as main source of water supply, food, fodder, fuel, fishery, aquaculture, timber production, transport, ecotourism, culture and heritage, research and educational values. The patterns of human occupancy and activity in the relatively narrow coastal strip have significantly affected the coastal environment.

Due to increased use of lakes and coastal environment and exploitation of their resources for various economic growths, these ecosystems are under severe stress. The stress may further increase in coming years because of urbanization, industrial growth, transportation, agriculture, housing etc. Unless timely corrective measures are taken, over-exploitation and environmental degradation will erode these ecosystems, which in turn will affect their productivity.

Various efforts are currently underway to develop technologies and systems for successful management of lakes and coastal environments—both at national and international levels. However, conflicting interests in the use of their resources have led to further worsening of the problems facing lakes and coastal environments. The important issues from a coastal environment perspective are livestock raising and agriculture in the coastal zone; the planning, control, and servicing of urban development in this area; the planning and assessment of major coastal facilities such as industrial projects, tourist

facilities, and ports; the development of fisheries in the coastal zone; and the conservation of coastal and near-shore natural resources. Therefore, it is very important to involve all of those concerned in the process of restoration, conservation and management of lakes and coastal environments. Thus, there is an imminent need to promote regional linkages, develop strategic partnership and follow good practices in the conservation and managements of lakes and coastal environments. It is also essential to establish new, and strengthen ongoing regional and international co-operation, linkages and strategic partnership between governments, international agencies, universities, research institutions, non-governmental organizations, private sectors, local communities, and individuals.

In view of the interdisciplinary approaches in the study of lakes and coastal environment and the rapid progress taking place in the concerned branches of science and engineering, it is hard for researchers to keep abreast with all the developments without periodic interactions and discussion. With the view to promote such an interaction, the Lake series conference, a biennial event, was started by the Karnataka Environment Research Foundation and the Centre for Ecological Sciences, Indian Institute of Science, Bangalore in the year 2000. The main objective was to provide a forum to present and share scientific knowledge in aquatic ecosystem conservation, restoration and management. Lake 2002, the second conference was organized by the Centre for Ecological Sciences, Indian Institute of Science, Bangalore. Lake 2004 is the third in the series. LAKE-2004, an international conference on "Conservation, Restoration and Management of Lakes and Coastal Wetlands", was organised in Bhubaneswar, Orissa during the period 9-13 December, 2004. Distinguished scientists, managers, social workers and administrators from across the world participated in the deliberations and discussions on different scientific and socio-economic aspects of lakes and coastal wetlands. Eminent scientists who have made significant contributions in their respective fields presented ten keynote lectures. A special session on Chilika Lake was arranged with two invited lectures. Besides, there were 65 oral presentations and 28 poster presentations on a wide range of topics such as biodiversity, coastal engineering, limnology, monitoring and modelling, remote sensing and geographical information system, water quality, watershed hydrology and hydrogeology, environmental protection laws and policy options, socio-economic considerations, people's participation and awareness, recreation and ecotourism and management aspects. This book is mainly an outcome of the conference LAKE-2004. The papers presented in the conference were peer reviewed by the editorial board and 18 papers mostly on monitoring and modelling aspects of lakes and coastal environment were included for publication in a book form.

I hope the book fulfils a gap in our current understanding and knowledge on monitoring and modelling lakes and coastal environments for their conservation, restoration and management. The book is intended as an appeal

to all scientists, managers and social workers to entertain a more global and holistic perspective and to adopt a macroscopic outlook on their approach to conservation, restoration and management of lakes and coastal environment.

I wish to record my sincere thanks to the organisers, co-organisers, sponsors and the scientific community for their active participation in the deliberation and discussion and for contributing papers to LAKE-2004 and to this book. The conference was organised by the Institute of Mathematics and Applications, Bhubaneswar. It was organised in co-operation with the Berhampur University, Berhampur; Chilika Development Authority, Bhubaneswar; Orissa Remote Sensing Application Centre, Bhubaneswar; Karnataka Environment Research Foundation, Bangalore; Centre for Ecological Sciences, Indian Institute of Science, Bangalore; and Centre for Atmospheric Sciences, IIT, Delhi. The organizing committee express their appreciation for the support afforded by the sponsors, the Commonwealth of Learning, Canada; Ministry of Environment and Forest, Government of India; Department of Science and Technology, Government of India; Department of Biotechnology, Government of India; Indian Space Research Organisation; Council of Scientific and Industrial Research, Government of India; Department of Ocean Development, Government of India; and the Indian Institute of Technology, Kharagpur. I am indebted to the members of the editorial board for their conscientious effort in reviewing the manuscripts, valuable suggestions and overall guidance in editing the book without which the publication would not have been possible.

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Contents

Eco-Restoration Impact on Fishery Biodiversity and Population Structure in Chilika Lake

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1. INTRODUCTION

Chilika lake is not only the largest coastal wetland and a much focused Ramsar Site of international importance but also a unique fragile brackishwater ecosystem of distinction being regarded as the store house of rich living aquatic resources and hot spot of biodiversity (Fig. 1). With unique ecological

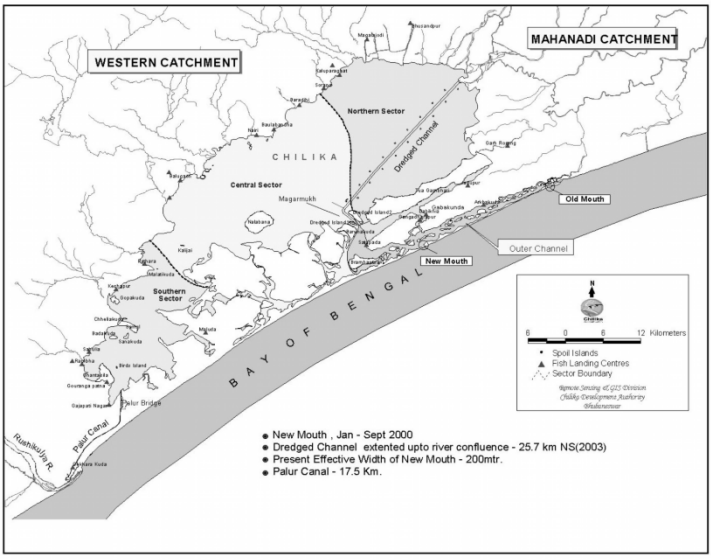

Figure 1: Map of Chilka lake showing four ecological sectors, hydrological connections, hydrological intervention and fish landing sampling centres.

characters resulting mostly from two antagonistic hydrological processes (freshwater inflow and sea water influx), Chilika has no parallel in the tropical world. The economic valuations of Chilika ecosystem has clearly established the importance of fisheries resources which accounts for more than 71% of the total valuation of the lake ecosystem (Ritesh Kumar, 2003), apart from providing food and livelihood securities to nearly 0.20 million people depending on lake fisheries. Fisheries of Chilika lake has been supporting the state economy and contributing to the earning of valuable foreign exchange to the extent of about 200 million rupees. However, fisheries of the lake suffered the most during the critical eco-degradation phase (last two decades) both in terms of yield and biodiversity status due to continued natural changes and unabated anthropogenic pressure.

Further, the first comprehensive study on faunal diversity was carried out by Zoological Survey of India (ZSI) during 1914-1924, and there was no further follow up except some fragmentary reports published during the later period (Trisal, 2000). The first organised fisheries investigation with holistic approach in Chilika lake was carried out by the Central Inland Fisheries Research Institute (CIFRI) during 1957-65 which has not been further followed up. Thus, during this forty years' gap and in the face of continued eco-degradation, no attempt has been made to study the lake fisheries including inventorisation of fishery biodiversity and population structure of fish and shellfish until the Chilika Development Authority (CDA) implemented the eco-restoration measures in 2000 by opening a new inlet mouth (lake mouth) at a shorter distance of 11 km from the lake proper and dredging the silt-choked Magarmukh area (Pattnaik, 2001). This hydrological intervention witnessed several positive impacts on the ecosystem including spectacular fisheries enhancement.

2. POST-NEW MOUTH MONITORING OF FISHERIES

With this background, the post-restoration monitoring of fisheries in the Chilika lake was carried out as a collaborative effort between CDA and the Department of Fisheries, Government of Orissa, since September, 2000 as a regular programme. Fish catch monitoring at all the 18 fish landing centres and all shrimp collection centres in the lake was carried out in an organized manner following systematic statistical sampling method (Biradar, 1988 and Gupta et al., 1991). Regular sampling of catches from different fishing gears at the fishing ground in four ecological sectors of the lake was also undertaken twice in every month at equal intervals to examine and collect the fish and shellfish species. Both catch/landing estimation and inventorisation of fish and shellfish faunal diversity were done during the monitoring. Further, the Chilika Lake was regularly monitored by the Fisheries Department of Orissa with a view to assessing the restoration impact on the fisheries output, four years catch data prior to and after the opening of new mouth were utilized.

3. YIELD SCENARIO

Data collected by the Department of Fisheries, Orissa indicated that the highest catch (8926 MT) during 1986-87 declined to 1274 MT during 1995-96, which was recorded as the lowest catch in the past. Jhingran and Natarajan (1969) suggested to separate prawn component from the fish component while collecting catch statistics in order to study the fishery trend judiciously. In the present study, prawns, shrimps and crabs were monitored as a separate 'shellfish' component and fish component (sharks, batoid fishes and bony fishes) were separately dealt with.

3.1 Prior to the Opening of the New Lake Mouth

Fish and shellfish (prawns, shrimps and crabs) landings in Chilika lake (1996-97 to 1999-00) prior to opening of the new lake mouth in September 2000 and after opening of the new lake mouth (2000-01 to 2003-04) were analyzed to study the impact of hydrological intervention on the fisheries of the lake. Pre-mouth data (averaged for four years) as presented in Table 1, shows drastically low fish and shellfish catch of 1489.07 MT and 197.29 MT respectively, which are less by 79.55% and 87.99% respectively from the fish and shellfish landings in 1986-87. This indicated that the prawn and crab fishery were more affected than fish during the period from 1987-88 to 1999-2000. Shellfish yield formed 11.70% in the total fisheries output during 1996-97 to 1999-2000 (Table 1). Cluepeoids, catfishes and mullets dominated the catch with 23.87%, 11.80% and 10.16% respectively. Freshwater fishes such as murrels, featherbacks and miscellaneous forage fishes together constituted 19.61% which was considerably higher. More freshwater condition and freshwater weed infested environment in the northern sector encouraged the population growth of murrels, featherbacks and weed fishes. One invasive freshwater species (*Oriochromis mosambica*) continued to propagate in the central sector and northern sector during the pre-mouth period under low salinity condition. Catch analysis for four years before new mouth indicated that the abundance of three fish groups (clupeoids, mullets and catfishes) were relatively stable despite faster degradation of the ecosystem. Mohanty et al. (2003), while evaluating commercial fish landings from Chilika lake (1997-98 to 1999-2000), reported that the northern sector, central sector, southern sector and outer channel sector shared 32%, 45%, 14% and 9% of the total catch respectively. Since penaeid prawns and portunid crabs breed in the sea and their juveniles are recruited from the sea into the lake, the prawn and crab population were decreased during this period due to recruitment failure as the lake mouth was shifted very far (about 30 km) from the lake proper and the confluence point of outer channel (recruitment route) at Magarmukh was silt-choked. The overall estimated productivity (fisheries output) was only 1.83 MT sq km^{-1} before restoration.

Table 1: Relative catch composition (by weight) of fish and shellfish in Chilika lake before and after opening of the new lake mouth (hydrological intervention)

Fish and shellfish of commercial importance (Group/species)	*Four years average catch (MT) before new mouth*		*Four years average catch (MT) after new mouth*		*% increase in Catch*	*% increase/ decrease in composition*
	Catch (MT)	*% Composition*	*Catch (MT)*	*% Composition*		
Fish						
Mullets	151.24	10.16	761.98	9.62	403.82	-5.31
Clupeoids	355.39	23.87	2254.13	28.47	534.27	19.27
Perches	132.89	8.92	458.24	5.79	244.83	-35.09
Threadfins (Polynemids)	67.65	4.54	336.62	4.25	397.59	-6.39
Croakers (Sciaenids)	101.64	6.83	741.18	9.36	629.22	37.04
Beloniformes (Needle fishes and Half beaks)	66.83	4.49	354.55	4.48	430.53	-0.22
Catfishes	175.74	11.80	1453.89	18.35	727.30	55.51
Tripod fish (*Triacanthes* Sp.)	46.98	3.15	402.49	5.08	756.73	61.27
Cichlids	98.81	6.63	296.05	3.74	199.61	-43.59
Murrels	55.49	3.73	187.39	2.37	237.70	-36.46
Feather backs (*Notopterus* sp.)	86.79	5.83	295.07	3.73	239.98	-36.02
Others	149.62	10.05	377.03	4.76	151.99	-52.64
Total fish landing	1489.07	100.00	7918.62	100.00	431.78	
Shellfish						
Penaeus monodon (Giant tiger prawn)	20.56	10.43	288.02	11.25	1300.87	7.86
Penaeus (Fenneropenaeus) Indicus (Indian white Shrimp)	27.39	13.86	421.25	16.45	1437.97	18.69
Metapenaeus monoceros (Brown Shrimp)	67.66	34.30	802.31	31.32	1085.80	-8.69
Metapenaeus dobsoni (Soft brown shrimp)	71.40	36.20	735.88	28.74	930.64	-20.61
Non-penaeid prawns (*Macrobrachium* sp.)	NA	NA	186.10	7.27	—	—
Mudcrabs (*Scylla* sp.)	10.28	5.21	127.48	4.97	1140.08	-4.61
Total shellfish landing	197.29	100.00	2561.04	100.00	1198.11	

NA – not available

3.2 After Opening of the New Lake Mouth

Post-new mouth monitoring of fisheries in the Chilika lake indicated that the hydrological intervention resulted in a far earlier recruitment of juvenile prawns and crabs into Chilika lake, and their retention for a longer period, presumably due to the maintenance of higher salinity and nutrient status for longer periods. Average catch for four years after opening of the new mouth (Table 1) worked out to 10,479.66 MT indicating 521.44% increase over pre-mouth data. Fish and shellfish catch during post restoration phase indicated spectacular leap with 431.78% and 1198.11% increase in comparison to the pre-restoration catch. Average yield as worked out from the average fisheries output (productivity) during post restoration period (2000-01 to 2003-04) was 11.35 MT $sqkm^{-1}$ which indicated 520.22% increase over pre-mouth data. Sector-wise catches indicated that the northern sector, central sector, southern sector and the outer channel sector contributed 41.84%, 47.13%, 8.86% and 2.17% respectively to the total catch. Compared to the pre-restoration situation, catches from northern sector and central sector were significantly increased during post-restoration period, which can be attributed to elevation in salinity gradient in these sectors and clearance of freshwater weeds from the northern sector. Fish populations, particularly those belonging to brackishwater habitat presumably were distributed more evenly in both central and northern sectors due to improvement in hydro-biological conditions after opening of the new mouth.

4. FISHERY BIODIVERSITY STATUS

The unique ecological complex, existence of four ecological sectors, adequate availability of natural food elements, openness of the lake to two hydrological systems (marine and freshwater) resulting in two antagonistic hydrological processes, with penetration of fish and shellfish faunas respectively from marine and inland origin and cyclical change of salinity gradient, provide diverse habitat conditions in Chilika lake for both migratory and resident/endemic fish and shellfish faunas with greater diversity.

The ZSI (1914-24), CIFRI (1957-65), other individual workers (1954-86), Chilika Expedition by ZSI (1985-87) and CDA (1998-2000) documented 225 fish species, 24 prawns and shrimps and 28 crab species as occurring in the Chilika lake before opening of the new mouth. Migration and movement of fish and shellfish faunas from the sea to lake and vice-versa, permanent resident species of brackishwater habitat within the lake, movement between brackishwater and freshwater mainly for feeding and breeding purposes exhibit diversities in habitats and nature of occurrence. Thus fishery biodiversity in Chilika lake needs to be studied in terms of species, habitats and occurrences.

4.1 Pre-restoration Status

During 1914-24, ZSI carried out the pioneering work on faunal diversity of Chilika lake and documented 112 fish species, 24 prawn and shrimps and 26 crab species (Chaudhuri, 1916a, 1916b, 1916c, 1917, 1923; Hora, 1923 and Kemp, 1915). During the first fisheries investigation in Chilika lake by CIFRI (1957-65) and by some individual workers during 1954-86, 101 fish species were documented from Chilika lake (Koumans, 1941; Jones and Sujansinghani, 1945; Mitra, 1946; Devasundaram, 1954; Roy and Sahoo, 1957; Menon, 1961, Mishra, 1962, 1969, 1976a, 1976b; Jhingran and Natarajan, 1966, 1969; Rajan et al., 1968; Mohanty, 1973; Talwar and Kacker, 1984; Talwar and Jhingran, 1991; Ramarao, 1995; Reddy, 1995; Maya Deb, 1995 and Bhatta et al., 2001). Thus, the pre-restoration status of species diversity in fish and shellfish faunas in Chilika lake stood at 225 fish species under 149 genera, 72 families and 16 orders, 24 prawn and shrimp species comprising 13 genera, nine families and two suborder and 28 crab species distributed under 22 genera, nine families and one suborder (Table 2). Fish species included four sharks, eight batoid fishes and 213 bony fishes. Twenty four recorded prawn and shrimp species included five number penaeid prawns and 19 number non-penaeid prawns. Among 28 recorded crab species, food crabs belong to three families (Calippidae, Portunidae and Grapsidae).

Prior to eco-restoration of Chilika lake, the ecosystem was under severe threats, most of which had roots to the natural changes and human-induced activities. During this phase, the migration and recruitment routes, habitats were considerably affected along with decline in salinity regime and proliferation of freshwater weeds in the northern sector. River mouths and Magarmukh were heavily silted to adversely affect the normal functioning of the ecosystem. Such conditions are likely to result in significant changes in faunal diversity and habitats. However, no attempt was made in the past to carry out inventorisation survey of fish and shellfish faunas in Chilika lake, which was most needed during eco-degradation phase. Further information on fishery biodiversity with reference to habitat and occurrence are not available except some limited account published by Biswas (1995) and Mohanty (2002). After reviewing literatures on icthyo-faunal records of Chilika lake, Khora (2002) reported that a good number of recorded species is overlooked, many are synonymied and some are invalid. Hence, a thorough inventorisation and review of literatures on the documented species of fish, prawn and crab before restoration of Chilika lake was considered imperative.

During 1985-87, while carrying out survey under Chilika Expedition Project, ZSI collected 63 recorded fishes, 13 prawns and 11 crab species and added four new records of fishes and two new records of crab species. Later, CDA carried out organized inventorisation survey and reported eight new records of fish species before opening of the new mouth (Bhatta et al., 2001). Thus, the inventorisation survey (Table 2) carried out before restoration

Table 2: Biodiversity status (Number of species) of fish and shellfish in Chilika lake during pre- and post-restoration (hydrological intervention) phases

Status parameter	*Pre-restoration survey (1914-2000)*	*Post-restoration survey (2000-01 to 2003-04)*	*Total of both phases*	*% increase*
1. Recorded species	By ZSI, CIFRI & individual workers	By CDA (New record)		
Fish	225 (G/149, F/72, O/16)	43 (G/38, F/31, O/14)	268 (G/168, F/82, O/20)	19.11
Shrimp & Prawn	24 (G/13, F/9, SO/2)	4 (G/3, F/2, SO/2)	28 (G/14, F/9, SO/2)	16.66
Lobster	Not recorded	2 (G/1, F/1, SO/1)	2 (G/1, F/1, SO/1)	00.00
Crab	28 (G/22, F/9, SO/1)	7 (G/5, F/3, SO/1)	35 (G/23, F/29, SO/1)	25.00
2. Inventorisation of recorded species	Last survey by ZSI (1985-87)	CDA survey (2000-01 to 2003-04)	Same as inventorisation CDA survey by	
Fish	71 (G/60, F/43, O/13)	187 (G/110, F/71, O/20)	187 (69.78%)*	163.38
Shrimp & Prawn	13 (G/6, F/5, SO/2)	18 (G/8, F/5, SO/2)	18 (64.28%)*	38.46
Lobster	No record	2 (G/1, F/1, SO/1) (First time record)	2 (100.00%)*	00.00
Crab	11 (G/11, F/6, SO/1)	14 (G/9, F/5, SO/1)	14 (40.00%)*	27.27

G – Genus; F – Family; O – Order; SO – Suborder; ZSI – Zoological Survey of India; CIFRI – Central Inland Fisheries Research Institute; CDA – Chilika Development Authority; *Figures in parenthesis indicate percentage to total record under column 4

reported collection of 71 fish species under 60 genera, 43 families and 13 orders, 13 prawns and shrimps distributed under six genera, five families and two sub-orders, and 11 crab species belonging to 11 genera, six families and one sub-order.

4.2 Post Restoration Status

The inventorisation survey for fish and shellfish faunas initiated by CDA during 1998 was continued in Chilika lake during the post restoration phase (Tables 3 and 4). In total, 187 fish species under 110 genera, 71 families and 20 orders, 18 prawn and shrimp species under eight genera, five families and two sub-orders and 14 crab species under nine genera, five families and one sub-order, totalling to 221 number of fish and shellfish species, were documented. The inventorisation survey during post-restoration phase indicated recovery of 69.78% fish, 64.28% prawns and shrimps, 100% lobsters and 40.00% crab species. For the first time, two species of Indian spiny lobsters (*Panulirus polyphagus* and *Panulirus ornatus*) under family Palinuridae and sub order Macrura were collected from the Chilika lake during 2003. A total of 56 new records of fish, prawn, shrimps, lobsters and crabs were documented along with collection of materials during 2000-01 to 2003-04. The new records (Table 4) include 43 number of fish species under 38 genera, 31 families and 14 orders, four number prawn and shrimps comprising three genera, two families and two sub orders, two lobster species under single genera, family and suborder and seven crab species belonging to five genera, three families and one sub order (Table 4). Inventorisation of already recorded species before restoration (Table 3) documented 144 fish species, 14 prawn and shrimp species and seven crab species totalling to 165 species of fish and shellfish along with collection of materials.

Biodiversity status with regard to habitat and occurrence of fish and shellfish faunas in Chilika lake as observed from the inventorisation survey carried out by ZSI during 1985-87 before restoration and survey conducted by CDA during 2000-01 to 2003-04 after restoration is documented in Table 5. Fish species belonging to marine-brackish water habitat continued to dominate both during pre- and post-restoration phases with 31.55% and 33.16% respectively. Similarly fishes belonging to brackishwater-marine and freshwater-brackish water habitats were stable in their composition during both phases. Relative abundance of freshwater species decreased from 14.67% during pre-restoration phase to 13.67% during post-restoration phase, while species moving from brackishwater to freshwater habitat were drastically reduced from 5.78% to 2.14%. Out of several penaeid shrimp species observed during post-restoration phase, five were commercial, contributing more than 94% to the total prawns and shrimps catch which constituted 20.84% in the prawn and shrimp faunal diversity. One freshwater prawn (*Macrobrachium malcolmasonii*) contributing to the commercial prawn catch constituted 8.33% of the faunal diversity. However, small sized prawns belonging to freshwater-

Table 3: Inventorisation of recorded fish and shellfish faunas of Chilika lake during post-restoration period

Family	*Species*	*H & O Status*
Fishes		
1 Carcharhinidae	1. *Scoliodon laticaudas* (Muller & Henle)	M,R
2 Dasyatididae	2. *Himantura uarnak* (Forsskal)	M,VR
	3. *Himantura walga* (Muller & Henle)	M,VR
3 Myliobatididae	4. *Aetobatus flagellum* (Bloch & Schneider)	M,VR
	5. *Aetomylaeus nichofii* (Bloch & Schneider)	M,R
4 Notopteridae	6. *Notopterus notopterus* (Pallas)*	F,A
	7. *Notopterus chitala* (Hamilton-Buchanan)	F,VR
5 Elopidae	8. *Elops machnata* (Forsskal)	BM,R
6 Megalopidae	9. *Megalops cyprinoides* (Broussonet)	BM,R
7 Anguillidae	10. *Anguilla bengalensis* (Gray)	MB,A
	11. *Anguilla bicolour bicolour* (Mc Clelland)	MB,R
8 Muraenidae	12. *Thyrsoidea macrura* (Bleeker)	M,R
9 Ophichthidae	13. *Pisodonophis boro* (Hamilton-Buchanan)	MB,R
10 Muraenesoscidae	14. *Muraenesox cinereus* (Forsskal)	MB,R
11 Clupeidae	15. *Anodontosoma chacunda* (Hamilton-Buchanan)*	MB,A
	16. *Corica soborna* (Hamilton-Buchanan)	B,R
	17. *Escualosa thoracata* (Valenciennes)	MB,R
	18. *Gonialosa manmina* (Hamilton-Buchanan)	MB,R
	19. *Gadusia chapra* (Hamilton-Buchanan)	F,A
	20. *Hilsa (Tenualosa)ilisha* (Hamilton-Buchanan)*	MB,A
	21. *Hilsa kelee* (cuvier)	MB,A
	22. *Nematalosa nasus* (Bloch)*	BM,A
12 Engraulidae	23. *Stolephorus bagenensis* Hardenberg	MB,A
	24. *Stolephorus commersonii* Lacepade	MB,A
	25. *Stolephorus dubiosus* Wongrantania*	MB,A
	26. *Stolephorus indicus* (Van Hasselt)	MB,R
	27. *Thryssa hamiltonii* (Gray)*	B,A
	28. *Thryssa mystax* (Schneider)	B,A
	29. *Thryssa polybranchialis* (Wongrantania)	MB,R
	30. *Thryssa purava* (Hamilton-Buchanan)	B,R
13 Chanidae	31. *Chanos chanos* (Forsskal)	BM,R
14 Cyprinidae	32. *Amblypharyngodon mola* (Hamilton)	F,R
	33. *Catla catla* (Hamilton-Buchanan)	F,R
	34. *Cirrhinus mrigala* (Hamilton-Buchanan)	F,R
	35. *Cirrhinus reba* (Hamilton-Buchanan)	F,R
	36. *Chela bacaila* (Hamilton-Buchanan)	F,R
	37. *Chela cachius* (Hamilton-Buchanan)	MB,R
	38. *Esomus danricus* (Hamilton-Buchanan)	B,R
	39. *Labeo rohita* (Hamilton-Buchanan)*	F,R
	40. *Labeo calbasu* (Hamilton-Buchanan)	FV,R
	41. *Puntius chola* (Hamilton-Buchanan)	FB,A
	42. *Puntius sarana* (Hamilton-Buchanan)	FB,R
	43. *Puntius sophore* (Hamilton-Buchanan)	FB,A
	44. *Puntius ticto* (Hamilton-Buchanan)	FB,A
	45. *Parluciosoma daniconius* (Hamilton-Buchanan)	B,R
	46. *Salmostoma bacaila* (Hamilton-Buchanan)	FB,R
15 Bagridae	47. *Aorichthys seenghala* (Sykes)*	F,R

(*contd.*)

Table 3 (*contd.*)

Family	*Species*	*H & O Status*
	48. *Mystus gulio* (Hamilton-Buchanan)*	BF,A
	49. *Mystus cavasius* (Hamilton-Buchanan)*	FB,R
16 Ariidae	50. *Mystus vittatus* (Bloch)	FB,R
	51. *Arius arius* (Hamilton-Buchanan)	MB,R
	52. *Arius tenuispinnis* Day	MB,R
	53. *Osteogeneniosus militaris* (Linnaeus)*	MB,A
17 Siluridae	54. *Ompok bimaculatus* (Bloch)	F,R
	55. *Ompok Pabda* (Hamilton)	F,R
	56. *Wallago attu* (Schneider)*	F,R
18 Schilbeidae	57. *Ailia coila* (Hamilton-Buchanan)	F,R
19 Pangasidae	58. *Pangasius pangasius* (Hamilton-Buchanan)	FB,A
20 Clariidae	59. *Clarias batrachus* (Linnaeus)	FB,R
21 Heteropneustidae	60. *Heteropneustes fossilis* (Bloch)	FB,R
22 Plotosidae	61. *Plotosus canius* (Hamilton-Buchanan)*	B,A
	62. *Plotosus lineatus* (Thunberg)*	B,A
23 Aplocheilidae	63. *Aplocheilus panchax* (Hamilton-Buchanan)	FB,A
24 Hemiramphidae	64. *Hyporhamphus limbatus* (Valenciennes)*	B,A
25 Belonidae	65. *Strongylura strongylura* (VanHasselt)*	B,A
	66. *Strongylura liura* (Blecker)*	FB,A
	67. *Xenentodon cancila* (Hamilton-Buchanan)	FB,A
26 Syngnathidae	68. *Hyppocampus brachyrhynchus* Duncker	MV,R
	69. *Ichthyocampus carce* (Hamilton-Buchanan)	BM,VR
27 Platycephalidae	70. *Platicephalus indicus* (Lineaeus)	MB,A
28 Centropomidae	71. *Lates calcarifer* (Bloch)*	MB,A
29 Ambassidae	72. *Ambassis commersoni cuvier*	MB,A
	73. *Ambassis gymnocephalus* (Lacepede)	MB,A
	74. *Chanda nama* (Hamilton-Buchanan)	MB,A
	75. *Pseudoambassi ranga* (Hamilton-Buchanan)	MB,A
30 Serranidae	76. *Epinephelus tauvina* (Forsskal)	M,R
31 Teraponidae	77. *Terapon jarbua* (Forsskal)*	MB,A
	78. *Terapon puta* (cuvier)*	MB,A
32 Sillaginidae	79. *Sillago sihama* (Forsskal)*	MB,A
33 Carangidae	80. *Carangoides paraeusteus* (Bennelt)	MB,A
	81. *Caranx carangus* (Bloch)	MB,A
	82. *Caranx sexfasciatus* (Quoy and Gairnard)	MB,R
	83. *Megalaspis cordyla* (Lineaeus)	B,R
	84. *Scomberoides tala* (Cuvier)	M,R
	85. *Selaroides leptolypis* (Cuvier)	M,R
34 Leiognathidae	86. *Leiognathus dussumieri* (Valenciennes)	M,A
	87. *Leiognathus equulus* (Forsskal)	M,A
35 Lutjanidae	88. *Lutjanus johni* (Bloch)*	MB,R
	89. *Lutjanus russelli* (Blecker)*	MB,R
	90. *Lutjanus argentimaculatus* (Forsskal)	MB,R
36 Datnioedidae	91. *Datnioides quadrifasciatus* (Sevastianov)*	B,A
37 Gerreidae	92. *Gerreomorpha setifer* (Hamilton-Buchanan)*	BM,A
	93. *Gerres oyena* (Forsskal)*	B,A
	94. *Gerres abbreviatus* (Blecker)	BM,R
	95. *Gerres filamentosus* (Cuvier)*	B,A
38 Haemulidae	96. *Pomadasys argenteus* (Forsskal)	MB,R

(*contd.*)

Table 3 (*contd.*)

39 Sparidae	97. *Acanthopagrus berda* (Forsskal)	MB,R
	98. *Crenidens crenidens* (Forsskal)*	MB,A
	99. *Rhabdosargus sarba* (forsskal)*	B,A
40 Sciaenidae	100. *Daysciaena albida* (Cuvier)*	MB,A
	101. *Dendrophysa russeli* (Cuvier)*	BM,A
	102. *Paranibea semilactuosa* (Cuvier)	M,R
	103. *Protonibea diacanthus* (Lacepede)	M,R
41 Monodactylidae	104. *Monodactylus argenteus* (Linnaeus)	M,R
42 Drepanidae	105. *Drepane punctatus* (Linnaeus)	MB,R
43 Scatophagidae	106. *Scatophagus argus* (Linnaeus)	MB,R
44 Nandidae	107. *Nandus nandus* (Hamilton-Buchanan)	B,R
45 Cichlidae	108. *Oriochromis mossambicus* (Peters)*	FB,A
	109. *Etroplus suratensis* (Bloch)*	
46 Mugilidae	110. *Liza macrolepis* (Smith)*	BM,A
	111. *Liza melinoptera* (Valancienues)*	BM,A
	112. *Liza parsia* (Hamilton-Buchanan)*	BM,A
	113. *Liza subviridis* (Valenciennes)*	BM,A
	114. *Liza tade* (Forsskal)	MB,R
	115. *Mugil cephalus* (Linnaeus)*	BM,A
	116. *Rhinomugil corsula* (Hamilton-Buchanan)*	FB,A
	117. *Valamugil cunnesius* (Valenceinnes)*	BM,A
	118. *Valamugil speigleri* (Blecker)	MB,A
47 Scombridae	119. *Scomberomorus linolatus* (Cuvier)	M,R
48 Polynemidae	120. *Eleutheronema tetradactylum* (Shaw)*	M,A
	121. *Polydactylus indicus* (Shaw)	MB,A
49 Gobiidae	122. *Acentrogobius cyanomos* (Blecker)	B,R
	123. *Acentrogobius globiceps* (Hora)	B,R
	124. *Glossogobius giuris* (Hamilton-Buchanan)	FB,R
	125. *Olegolepis cylindriceps* (Hora)	BF,R
	126. *Oxyurichthys microlepis* (Blecker)	MB,VR
50 Trypauchenidae	127. *Tripauchen vagina* (Bloch and Schneider)	MB,VR
51 Siganidae	128. *Siganus javus* (Linnaeus)	MB,R
52 Anabantidae	129. *Anabas testudineus* (Bloch)	F,R
	130. *Anabas cobojius* (Hamilton-Buchanan)	F,VR
53 Belontidae	131. *Colisa fasciatus* (Schneider)	F,R
	132. *Colisa lalia* (Hamilton)	F,R
54 Channidae	133. *Channa striatus* (Bloch)*	FB,A
	134. *Channa punctatus* (Bloch)	FB,A
55 Mastacembelidae	135. *Macrognathus pancalus* (Hamilton-Buchanan)*	BF,A
	136. *Mastacembelus armatus* (lacepede)*	BF,R
56 Bothidae	137. *Pseudorhombus arius* (Hamilton-Buchanan)	MB,R
57 Cynoglossidae	138. *Cynoglossus puncticeps* (Richardson)	MB,A
58 Soleidae	139. *Euryglossa orientalis* (Bloch)	MB,R
59 Tricanthidae	140. *Triacanthus biaculeatus* (Bloch)*	B,A
60 Tetradontidae	141. *Chelonodon fluviatilis* (Hamilton-Buchanan)	MB,R
	142. *Chelonodon patoca* (Hamilton-Buchanan)	MB,R
	143. *Tetradon cutcutia* (Hamilton-Buchanan)	MB,R
	144. *Takifugu oblongus* (Bloch)	MB,R
Shrimps and Prawns		
1 Penaeidae	1. *Metapenaeus affinis* (H.Milne-Edwards)	MB,R

(*contd..*)

Table 3 (*contd.*)

Family	*Species*	*H & O Status*
	2. *Metapenaeus dobsoni* (Miers)*	BM,A
	3. *Metapenaeus monoceros* (Fabricius)*	BM,A
	4. *Penaeus(Fenneropenaeus) indicus*(H.Milne-Edwards)*	BM,A
	5. *Penaeus monodon* (Fabricius)*	BM,A
	6. *Penaeus Semisulcatus* (de-Haan)*	BM,R
2 Palaemonidae	7. *Macrobrachium lamarrei* (H.Milne-Edwards)*	B,A
	8. *Macrobrachium malcomsonii* (H.Milne-Edwards)*	F,R
	9. *Macrobrachium rude* (Heller)*	B,A
	10. *Exopalaemon styliferus* (H.Milne-Edwards)	FB,R
	11. *Periclimenes (Harpilius) demani* Kemp.	BB,R
3 Atyidae	12. *Caridina propinqua* de Man	BF,VR
4 Callianassidae	13. *Callianassa (Callichirus)maxima* H.Milne-Edwards	B,VR
5 Upogebiidae	14. *Upogebia (Upogebia) heterocheir* Kemp.	FB,VR
Crabs		
1 Calappidae	1. *Matuta planipes* Fabricus	MB,R
2 Leucosiidae	2. *Philyra alcocki* Kemp.	MB,VR
3 Ocypodidae	3. *Ocypoda macroara* (H.Milne-Edwards)	MB,R
4 Grapsidae	4. *Varuna litterate* (Fabricius)	MB,R
5 Portunidae	5. *Portunus pelagicus* (Linnaeus)*	MB,A
	6. *Scylla serrata* (forsskal)*	BM,A
	7. *Thalamita crenata* (Latre)	MB,A

* Commercial species; H&O: habitat and occurrence; M: marine; B: brackishwater; F: freshwater; MB: marine-brackishwater; BM: brackishwater-marine; FB: freshwater-brackishwater; BF: brackishwater-freshwater

brackishwater-freshwater habitat constituted 55.78% of the total prawn species before restoration. Shrimp species belonging to the Marine-brackishwater-marine habitat were increased during post-restoration phase forming 44.45%. One commercially important freshwater prawn (*Macrobrachium rosenbergii*) was found as a new record during post-restoration period. All crab species collected during pre- and post-new mouth phases belonged to marine-brackishwater-marine habitat. One species of mudcrab (*Scylla tranquebarica*), although was occurring in Chilika lake since the faunal diversity study by ZSI during 1914-24, it was hitherto not reported/documented as a separate mudcrab species, different from the commonly occurring species *Scylla serrata*. The species, *Scylla tranquebarica* (Fabr.) was earlier regarded as one of the four varieties of one mudcrab species, *Scylla serrata*. This controversy of species identification of the mudcrabs in the genus *Scylla* was ended when Fuseya and Watanabe (1996) and Fushimi and Watanabe (1999) confirmed by genetic variability studies in Japan that *Scylla tranquebarica* is distinctively a separate mudcrab species. Hence, this mudcrab species has been added as a new record to the crab faunas of Chilika lake during post restoration phases. Species diversity composition based on the status of occurrence (Table 5) indicated that abundantly occurring fish, prawn and

Table 4: New records of fishes, shrimps and prawns and crabs from Chilika lake after recent hydrological intervention during 2000-01 to 2003-04

Order	*Suborder*	*Family*	*Species*	*H & O Status*
Fish				
Carcharhiniformes (Ground sharks & allies)	Scyliorhinoidei	Sphyrnidae	1. *Sphyrna lewini* (Griffith and Smith)	M,VR
			2. *Sphyrnablochii* (Cuvier)	M,VR
Rajiformes (Skates & rays)		Rhinobatidae	3. *Rhynchobatus djeddensis* (Forsskal)	M,R
Myliobatiformes (Sting rays)		Dasyatididae	4. *Dasyatis marginatus* (Blyth)	M,R
Anguilliformes (Eels)	Anguilloidei	Muraenesocidae	5. *Muraenesox bagio* (Hamilton)	B,R
Clupeiformes (Herrings, Sardins, Shads & allies)	Clupeoidei	Clupeidae	6. *Sardinella fimbriatus* (Valenciennes)	M,VR
			7. *Sardinella longiceps* (Vol)	M,VR
			8. *Dussumieria elopsides* (Blecker)	B,R
			9. *Ehirava fluviatilis* Deraniyagala	MB,VR
			10. *Thryssa gautamiensis* (B. Rao)	MB,R
			11. *Thryssa setirostris* (Broussonet)	MB,A
Cypriniformes (Carps & minnows)	Cyprinoidei	Cyprinidae	12. *Labeo boga* (Hamilton)	F,R
			13. *Labeo gonius* (Hamilton)	F,R
			14. *Osteobrama cotio peninssularis* Silas.	F,VR
Siluriformes (Catfishes)		Sisoridae	15. *Bagarius yarellii* Sykes	F,R
Aulopiformes (Green eyes, Lizard fish and allies)		Synodontidae	16. *Trachinocephalus myops* (Forster)	M,VR
Atheriniformes (Silver sides)		Atherinidae	17. *Atherinomorous lacunosus* (Forster)	M,VR
			18. *Atherinomorus duodecimalis* (Valenciennes)	M,VR
Syngnathiformes (Pipe fishes)	Syngnathoidei	Syngnathidae	19. *Syngnathus cynospilus* Blecker	M,VR

(*contd..*)

Table 4 (*contd.*)

Order	*Suborder*	*Family*	*Species*	*H & O Status*
Synbranchiformes (Shore eels)		Synbranchidae	20. *Ophisternon bengalense* Mc Clelland	M,VR
Scorpaeniformes (Scorpion fishes & allies)	Scorpinoidei	Tetrarogidae	21. *Tetraroge niger* (Cuvier)	MB,R
			22. *Sugrundus rodri censis* (cuvier)	MB,VR
Perciformes (Perch-like fishes)	Percoidei	Serranidae	23. *Epinephelus coioides* (Hamilton)	M,R
		Sillaginidae	24. *Sillago vincenti* Mc. Kay	MB,VR
		carangidae	25. *Scomberoides commersonianus* (Lacepede)	M,VR
			26. *Scomberoides tol* (cuvier)	M,VR
			27. *Selar crumenophthalmus* (Bloch)	M,VR
			28. *Trachinotus mookalee* (Cuvier)	M,VR
		Leiognathi-dae	29. *Leiognathus bindus* (Valenciennes)	M,VR
		Gerreidae	30. *Gerres abbreviatus* (Blecker)	MB,VR
		Haemulidae	31. *Pomadasys kaakan* (Cuvier)	M,R
		Cichlidae	32. *Oriochromis mossambica* (Peters)	F,A
	Scombroidei	Trichuridae	33. *Eupleurogrammus glossodon* Blecker	M,VR
			34. *Lepturacanthus savala* (Cuvier)	M,VR
		Scombridae	35. *Rastrelliger kanagurta* (Cuvier)	M,VR
	Sphyraenoidei	Sphyraenidae	36. *Sphyraena jello* (Cuvier)	M,VR
	Polynemoidei	Polynemidae	37. *Polydactylus plebeius* (Broussonet)	MB,VR
	Gobioidei	Eleotridae	38. *Eleotris melanosoma* Blecker	M,VR
		Gobiidae	39. *Yongeichthys criniger* (Valenciennes)	B,VR
	Acanthuroidei	Acanthuridae	40. *Acanthurus mata* (Cuvier)	M,VR
		Siganidae	41. *Siganus canaliculatus* (Park)	M,R

(*contd..*)

Table 4 (*contd.*)

	Channoidei	Channidae	42. *Channa marulius* (Hamilton)	F,R
Pleuronectiformes (Left eye flounders)	Pleuronectodoidei	Bothidae	43. *Pseudorhombus triocellatus* (Bloch)	M,R
Shrimp/Prawn				
Decapoda	Penaeoidea	Penaeidae	1. *Penaeus (Melicertes) canaliculatus* (Oliver)	MB,R
			2. *Metapenaeus ensis* DeHaan	MB,R
	Caridea	Palaemonidae	3. *Macrobrachium rosenbergii* (DeMan)	F,R
			4. *Macrobrachium equidens* (Dana)	B,R
Lobster				
Decapoda	Macrura	Palinuridae	1. *Panulirus polyphagus* (Herbst)	M,VR
			2. *Panulirus ornatus* (Fabricius)	M,VR
Crab				
Decapoda	Brachyura	Portunidae	1. *Charybdis cruciata* (Herbst)	MB,R
			2. *Charybdis callianasa* (Herbst)	MB,R
			3. *Portunus sanguinolentus* (Herbst)	BM,A
			4. *Scylla tranquebarica* (Fabricius)	BM,A
			5. *Podophthalmus vigil* (Herbst)	MB,R
		Grapsidae	6. *Sesarma quadrata* (Fabricius)	MB
		Calappidae	7. *Mutata lunaris* (Forsskal)	MB

H&O: habitat and occurrence; M: marine; B: brackishwater; F: freshwater; MB: marine-brackishwater; BM: brackishwater-marine; FB: freshwater-brackishwater; BF: brackishwater-freshwater; R: rare; A: abundant; VR: very rare

Table 5: Biodiversity status (habitat and occurrence) of fish and shellfish in Chilika lake during pre- and post-restoration phases

Status parameter	*Pre-restoration (1914-2000)*			*Post-restoration (2000/01-2003/04)*			
	'Recorded species'			*'Inventorised species'*			
	Fish	*Shrimp & Prawn*	*Crab*	*Fish*	*Shrimp & Prawn*	*Lobster*	*Crab*
Percentage composition of species by habitat (%)							
Marine	21.33			21.93	5.55	100.00	
Brackishwater	9.78	8.33		11.76	33.33		
Freshwater	14.67	8.33		13.37	11.11		
Marine-Brackishwater	31.55	12.50	92.86	33.16	16.67		85.71
Brackishwater-Marine	5.78	20.84	7.14	5.88	27.78		14.29
Freshwater-Brackishwater	11.11	50.00		11.76	5.56		
Brackishwater-Freshwater	5.78			2.14			
Percentage composition of species by occurrence (%)							
Abundant	14.22	33.33	7.14	34.23	38.89		21.43
Rare	49.78	37.50	14.28	41.71	33.33		28.57
Very rare	36.00	29.17	78.58	24.06	27.78	100.00	50.00

Inventorisation of species during pre- and post-restoration phases are taken into consideration.

crab species increased during post-restoration phase. Abundantly occurring fish and crab species during pre-new mouth period increased significantly from 14.22 to 34.23% and from 7.14 to 21.43% respectively during post-new mouth period.

4.3 Species Richness

Species richness of estuaries and lagoons is defined as the number of species encountered at least once within ecosystem limits (Baran, 2000). Species richness (SR) in such aquatic ecosystems is dependant on the openness of the systems and characteristics of the spatio-temporal variation in salinity gradient. Chilika lake, which is estuarine in character, being influenced by three hydrological systems exhibits four distinctive ecological sectors. These four sectors show variations in species richness varying with the seasons. As observed from the species inventorisation survey undertaken during post-new mouth period, three sectors (northern, central and outer channel sectors) were more influenced by two antagonistic hydrological process resulting from freshwater inflow from rivers and catchment streams and sea water

ingress from the sea. Freshwater inflow into the lake remains active and strong during June-November. Although low/feeble inflow of freshwater from rivers continues throughout the year, the sea water influx dominate during December-May. Therefore freshwater species in northern sector are gradually replaced by brackish water species from December onwards which are again gradually replaced by freshwater species coming in the river flows from July onwards. Similarly the outer channel sector is strongly influenced by both freshwater outflow and the sea water ingress during semi-diurnal flow tides. Therefore, the species richness of fish and shellfish faunas in those sectors showed wider variations, whereas least variation was observed in the southern sector due to weak freshwater inflow for shorter duration and restricted exchange of water through Palur canal (before renovation).

After opening of the new mouth near Ramabhartia, enhancement in species richness was observed, particularly in outer channel sector. Outer channel sector registered the highest species richness (62.44%) in summer and 54.75% in winter. Central sector came in the second order with 48.42-50.68% SR. Northern sector registered SR of 34% only during winter. Southern sector showed minimum variation (14.93-16.74%) in species richness. Higher species richness in the outer channel sector is due to entry of more marine species during summer and winter for feeding purposes, except few others for breeding (*Eleutheronema tetradactylum*, some *clupeoides* etc.). In general, the species richness is mostly due to a succession of species temporarily using these ecological sectors for feeding, spawning or shelter. Dominance of marine or freshwater species in the ecosystem depends on the strength of marine and freshwater.

5. POPULATION STRUCTURE

In estuarine ecosystem, the fish and shellfish population is structured according to a gradient of increasing or decreasing salinity (Baran, 2000). Analysis of commercial catches from Chilika lake during pre and post-restoration phases indicated the percentage compositions (by weight of catch) of different commercial fish groups (Table 1). The commercial fish catch is contributed by 12 fish groups namely, mullets, clupeoides, perches, threadfins, croakers, beloniformes, catfishes, tripodfish, cichlids, murrels, featherbacks and others. These 12 fish groups comprised 22 species before opening of new mouth, which were increased to 46 species during post new mouth period (Table 3) indicating 109.09% increase. Similarly, prawns and crabs showed 60.0% and 50.0% increase respectively during the post restoration period. Species of fish and shellfish contributing to the bulk of catches during post-restoration phase are presented in Table 3. Clupeoids continued to dominate the fish catch forming 23.87% and 28.47% during pre- and post-restoration phases respectively. Catfishes and mullets came in the second and third order respectively before and after the New Mouth. Clupeids in estuaries generally dominate the fish catch. Baran (2000) reported that in African estuaries