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Long-Term Records of Fisheries Yield and Stocking in Kaptai Reservoir (Bangladesh)

—Evidence for Regime Shift?

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Abstract

Regime shifts, abrupt switches between alternate states of ecosystems, have repeatedly been described for marine fisheries, but little evidence exists for regime shifts in freshwater fisheries systems. A 41-year long time series (from 1965 until 2005) of fisheries yielded 17 fish species, dried fish and miscellaneous species from Kaptai reservoir, Bangladesh, which were analyzed to detect major trends in fish assemblage composition. Annual rates of supplemental stocking were included to elucidate whether stocking modified fish assemblage structure. Indian major carp species (ruhu, catla, mrigal, kalibaus), which dominated initially, were replaced by pelagic clupeid species (chapila, kechki) after about 20 years. Ordination of time series by nonmetric multidimensional scaling indicated smooth transitions between 1965 and 1980, but demonstrated rather drastic jumps between 1980 and 1986. Afterward, the system's succession became continuous again, indicating that a regime shift may have occurred between 1980 and 1986. Massive supplemental stocking with major carp fingerlings (ruhu, catla, mrigal) did not reverse the situation, but rather seemed to accelerate the switch. Drastic changes in fish assemblage composition coincided with low water levels in the reservoir in the previous years, thus indicating that blocked access to river spawning grounds due to low water levels may have contributed to the decline of major carp. Accordingly, the regime shift may have been caused by recruitment over-fishing of target fish species (mainly major carp), limitation of natural reproduction by low connectivity of the reservoir to river spawning grounds, failure of supplemental stocking programmes, competition between native and invasive species and ineffectiveness in implementing existing fishing regulations. Perspectives for a more efficient management of these important freshwater fisheries are discussed.

Subject Areas

Hydrology

Keywords

Regime Shift, Reservoir Ecosystem, Supplemental Stocking, Major Carp, Clupeid Species

1. Introduction

Abrupt ecosystem changes detected in long-term datasets have occurred in several ecosystems worldwide, and have been termed regime shifts [1]-[4]. Regime shifts are characterized as an event during which the ecosystem changes from one state to another over a rather short time period by crossing a threshold at which the quality and direction of feedback processes abruptly change [3] [5]-[7]. Once the "regime" has changed, it may stably persist over longer periods in the alternative state. Three different types of regime shift (smooth, abrupt and discontinuous) were identified [8] on the basis of different patterns in the relationship between the response of an ecosystem variable (usually biotic) and some external forcing or condition (control variable). Discontinuous regime shifts are particularly important to be recognized since they may not be immediately reversible.

Regime shifts were also detected in long-term harvest records from marine commercial fisheries. They have been attributed to a striking change in oceanographic conditions [9]. The global scale climatic regime shift (CRS) resulted in alterations to the oceanic environment that were followed by temporal and spatial changes in marine ecosystems and fisheries resources in the North Pacific [10]-[13] and North Sea [14]. Regime shifts in 1977 and 1989 also affected the catch and recruitment of fish resources viz. salmon, sardine, herring, saury and common squid in Japanese waters [7] [15]-[18]. Shifts from ecosystems dominated by demersal fish to ecosystems dominated by pelagic fish have been documented in the Atlantic and the Baltic Sea [19]-[21] and other coastal ecosystems [22] [23]. Most of these detailed studies have focused on marine fisheries resources. In contrast, less is known about regime shifts in inland freshwater fisheries. However, protein supply by inland fisheries is economically highly important in many Asian and African countries [24], and identifying regime shifts in inland fisheries is therefore of high interest to local fisheries managers.

Here, we present long-term data on fisheries yield from a large freshwater lake, Kaptai reservoir, in Bangladesh. A considerable number of people living in surrounding areas depend on the fisheries resources in this reservoir for their livelihood. Despite the great socio-economic value of the local fisheries, previous work primarily focused on biological and limnological aspects of the Kaptai reservoir [25]-[30] with limited studies on fish and fisheries [31]-[34]. In contrast, the present paper provides a multivariate analysis of the time series of the fisheries yield and fish stocking of major fish species in Kaptai reservoir over 40 years, and discusses constraints and potentials for improvement of the fish assemblage as an important source of high value freshwater fisheries.

2. Materials and Methods

2.1. Description of Study Site

Kaptai reservoir in Bangladesh (22˚22' - 23˚18'N; 92˚00' - 92˚26'E), one of the major man-made freshwater reservoirs in South-east Asia, was created in 1961 by damming the river Karnafuli at Kaptai in the Chittagong Hill Tracts (**Figure 1**).

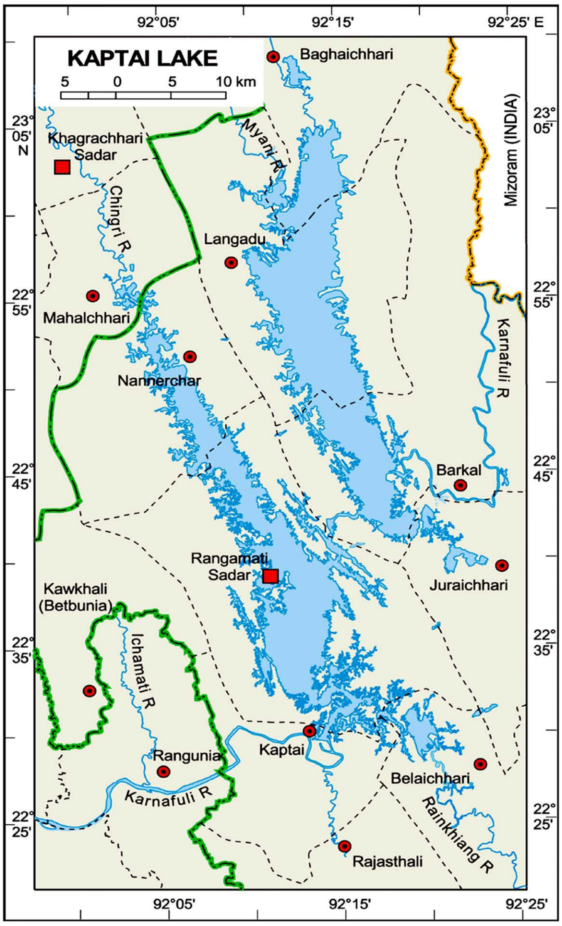

Figure 1. Geographical map of Kaptai reservoir, Bangladesh.

The primary purpose of the reservoir was hydropower generation, while fisheries, navigation, flood control and irrigation were facilitated additionally. Occupying a surface area of approximately 58,300 ha (68,800 ha at full supply level) and an average volume of 524.7×10^6 m^3 [35], this reservoir constitutes a significant component of inland water resources accounting for 46.8% of the total pond area of Bangladesh. The maximum and mean depths of the reservoir are 35 and 9 m respectively, with a mean annual water level fluctuation of 8.14 m [28]. The shoreline of the reservoir is rocky and strewn with remnants of submerged wooden logs and hillocks. In the shallow regions, submerged macrophytes, e.g., *Najas najas*, are abundant. Major land uses around the reservoir are slash and burn agriculture and forestry (teak plantation).

Kaptai reservoir is rich in its diversity of fish species. At present, a total of 73 fish species belong to 47 genera and 25 families. Of them, 31 species have commercial importance, but the annual yields of all species are not satisfactory at present. Furthermore, two species of prawn and one species of dolphin were identified [36].

The Department of Fisheries (DoF) initially managed the reservoir (1961-1963), but responsibility was transferred to the Bangladesh Fisheries Development Corporation (BFDC) in 1964. The fishery is leased to BFDC for 99 years. The corporation manages the ice plants and landing stations, where it collects royalties from catches, stocks the reservoir with fingerlings of major carps, issues fishing licenses and enforces fishing regulations. Bangladesh Fisheries Research Institute, Riverine Sub-Station [37] estimated that 679 gill nets, 305 seine nets, 93 lift nets, 18 push nets and 212 hooks and lines of different categories were applied to catch fish from the reservoir. Also, an estimated 1,000 brush shelters (a fish aggregating device) are operated annually in the reservoir and 5,560 fishers are engaged in overall fishing operation [36]. Provision for gear licensing in Kaptai reservoir first started in 1981, and only licensed fishers are allowed to fish in the reservoir. But, when compliance was checked through a survey, only 29% of the fishers had fishing licenses during 1997 [36].

A considerable number (about 10,000) of people depend on this reservoir for their livelihood. Kaptai Reservoir in Bangladesh basically supports artisanal to medium-scale commercial fisheries. Other than during the fishing ban period (June-August), fishing takes place every day. Concomitant with the multispecies nature of the lake's fishery, a variety of traditional fishing gears is used to capture the fish, for example lift nets (*dharma jal*), mosquito seine nets (*kechki jal*), large meshed gill nets (*vasha jal*), small meshed gill nets (*current net*), cluster hooks (*jhoomka borshi*), long lines (*chara borshi*), hand lines (*chip borshi*) and reel lines (*wheel borshi*).

2.2. Time Series

Annual catches (metric tons) of seventeen commercially important major fish species of Kaptai reservoir (**Table 1**) and summed catches of miscellaneous (tengra, pabda, bashpata, shing, magur, koi, baim, gajar, soal, taki, poa, phaisa, dhela, kajori, chela, kakila, chanda, batasi, carpio, silver carp, grass carp, swarpunti, prawn and baila) and dried fish (mainly composed of two species of clupeids and fingerlings of major carp) were collected from the landing records of Bangladesh Fisheries Development Corporation (BFDC), Kaptai Reservoir Projects, Rangamati Hill Tracts and Bangladesh Fisheries Research Institute (BFRI), Riverine Sub-Station (RSS), Rangamati Hill Tracts respectively for a period of 41 years (1965/66-2005/06). BFDC records the daily fish catches from two landing stations, one located at

Rangamati and another at Kaptai. Accordingly, species which did not appear in the catch were likely not present in the lake, whereas introduced species quickly became a recorded part of the catch. For example, the non-native tilapia has been recorded since 1986, following its accidental abortive introduction from experimental net cages in 1985. The category "dried fish" has been recorded since 1981-82 by the fish landing center (Rangamati) of BFDC. These fish have been accounted for in the analysis due to their significant contribution to the total landings along with fresh fish. Due to the large variety of fishing gear used, annual fisheries effort certainly varies, but the dimension of variation is completely unknown.

Furthermore, the annual intensity (individuals) of supplemental stocking with Indian major carp species (mrigal, catla, ruhu) was recorded over 36 years (1965/66-2001/02). Fish are stocked as fingerlings (size range 9 to 13 cm), produced artificially from mature fish (not originating from Kaptai reservoir) in entrepreneurs' hatcheries nearly 200 km away from Kaptai reservoir. In the subsequent text, we use the local names of all fish species. Common and scientific names and some ecological data on the species are listed in **Table 1**.

Table 1. Overview of local, common and scientific names and some ecological traits of commercially important fish species in Kaptai reservoir (Bangladesh).

Group name	Family name	Local name	Common name	Scientific name	Feeding mode	Maximum length (mm)
Major carp	Cyprinidae	Ruhu	Carp	*Labeo rohita* (Hamilton)	Planktivore	940
Major carp	Cyprinidae	Mahasoal	Carp	*Tor tor* (Hamilton)	Planktivore	520
Major carp	Cyprinidae	Catla	Carp	*Catla catla* (Hamilton)	Planktivore	967
Major carp	Cyprinidae	Mrigal	Carp	*Cirrhinus cirrhosus* (Bloch)	Benthivore	840
Major carp	Cyprinidae	Kalibaus	Carp	*Labeo calbasu* (Hamilton)	Benthivore	710
Minor carp	Cyprinidae	Gonia	Carp	*Labeo gonius* (Hamilton)	Planktivore	610
Minor carp	Cyprinidae	Bata	Carp	*Labeo bata* (Hamilton)	Planktivore	290
Minor carp	Cyprinidae	Punti	Barbs	*Barbodes sarana* (Hamilton)	Omnivore	420
Notopterid	Notopteridae	Chital	Featherback	*Notopterus chitala* (Hamilton)	Carnivore	1030
Notopterid	Notopteridae	Fali	Featherback	*Notopterus notopterus* (Pallas)	Carnivore	355
Cichlid	Cichlidae	Nilotica	Tilapia	*Oreochromis niloticus* (Linnaeus)	Omnivore	640
Catfish	Bagridae	Air	Catfish	*Aorichthys aor* (Hamilton)	Carnivore	940
Clupeid	Clupeidae	Kechki	Shad	*Corica soborna* (Hamilton)	Planktivore	35
Clupeid	Clupeidae	Chapila	Shad	*Gudusia chapra* (Hamilton)	Planktivore	200
Silurid	Siluridae	Boal	Freshwater shark	*Wallago attu* (Schneider)	Carnivore	1800
Schilbeid	Schilbeidae	Vacha	Catfish	*Eutropiichthys vacha* (Hamilton)	Omnivore	300
Cyprinid	Cyprinidae	Mola	Minnows	*Amblypharyngodon mola* (Hamilton)	Planktivore	90

2.3. Data Analyses

To identify major shifts in fisheries yield over the years, and to evaluate whether stocking has contributed to assemblage shifts, time series data was exposed to ordination by non-metric multidimensional scaling (NMS). This multivariate procedure was used to detect abrupt change-points in the time series [38]. NMS is an iterative search for the best positions of n entities on k axes minimising the stress of the k-dimensional configuration. Evaluation of whether the NMS extracts stronger axes than expected by chance is performed by a randomisation procedure (Monte-Carlo test). The primary matrix contained the annual catches of 17 fish species and groups of unidentified fish over a total of 40 years. NMS was run with the Sørensen distance, by using a random start configuration, a step-down from six dimensions to one, an instability criterion of 0.0001, 250 iterations to reach stability, 100 runs with the real data set, and 100 runs within the Monte-Carlo permutation procedure. The optimum dimensionality of the solutions was checked by a scree plot of stress versus dimensionality. Kendall's tau correlation coefficients were calculated between species-specific time series and the significant ordination axes. In the same way, the annual stocking intensity of major carps (mrigal, catla, ruhu, and total stocking) was correlated to the significant ordination axes. To account for potential time lags between stocking year and change in the fisheries yields, correlations were also calculated by shifting the time series of stocking successively forward up to a maximum of five years (lags + 1 to + 5 years). Ordination was performed by PC-ORD (version 5.01; MjM software design, USA) [39].

Data on monthly water level fluctuations in Kaptai reservoir were available only for the period 1979 - 1998. Therefore, we did not include these data directly in the ordination, but we calculated linear correlations between the annual differences in year scores from the ordination and the annual mean water levels over these 20 years. We hypothesized that, if the water level was decisive for modifications in the fish assemblage, year-to-year changes of the ordination scores were higher in years with extraordinarily high or low water levels. To account for potential time lags in the response of the fish assemblage, correlations were also calculated between annual water levels and the annual differences in ordination scores of the subsequent two years (time lag + 1 and + 2 years).

3. Results

Records of landing show that the fisheries yield from Kaptai reservoir grew at an estimated annual rate of 3.0% from the first harvest in 1965 to 2005. The average annual landing was 3.7×10^3 tons, with large variation between years (SD $\pm 1.33 \times 10^3$ tons). The maximum annual yield (6.6×10^3 tons) was obtained in 1997 - 1998. The mean yield was estimated at 63.5 kg^{-1} ha, with large variation over time (**Figure 2**).

Catches of major carp species fluctuated at a high level from 1965 to 1982, but declined dramatically afterwards (**Figure 2(a)**). In contrast, the annual yield of clupeids (kechki, chapila; **Figure 2(b)**) and of miscellaneous and dried fish

(Figure 2(d)) increased substantially from 1982 until 2005. For a number of Bagridae, Cichlidae and Notopteridae, the catch remained relatively constant over the total period (Figure 2(c)). Stocking of major carp species (ruhu, catla, mrigal) was conducted over all years between 1964 and 2002. However, stocking intensity was substantially increased from 1984 onwards (Figure 3), peaking at about 58.6 × 10^6 fingerlings in 1992.

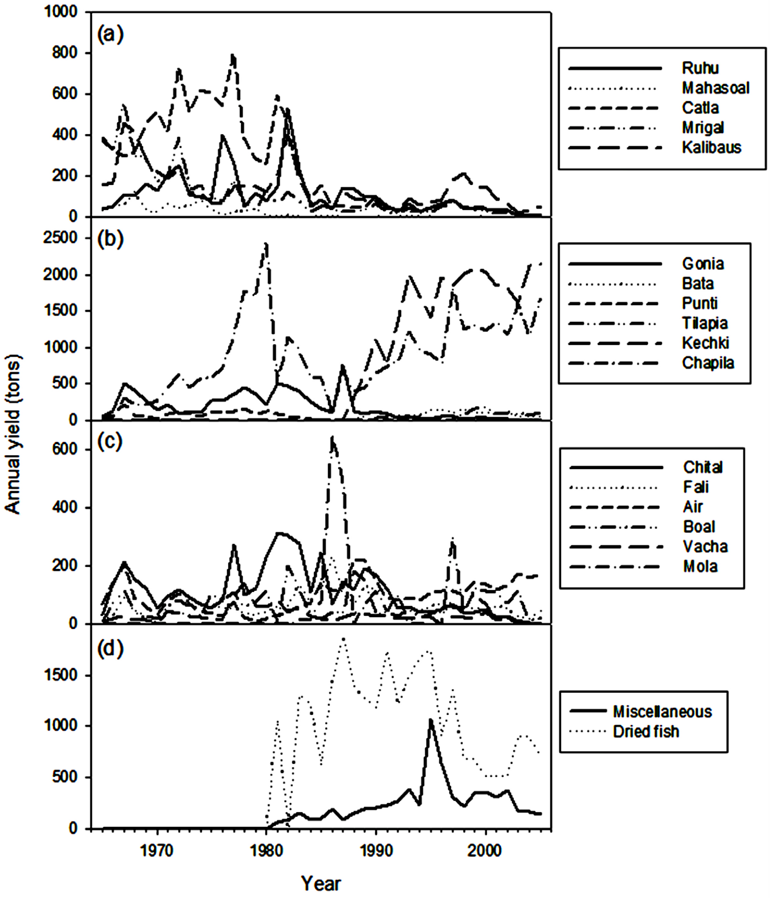

Figure 2. Time series of annual fisheries yield (tons) of Indian major carp species (ruhu, mahasoal, catla, mrigal, kalibaus) (a), of Indian minor carp (gonia, bata, punti), tilapia and clupeids (kechki, chapila) (b), of notopterids (chital, fali), catfish (air, boal, vacha) and cyprinids (mola) (c), and of miscellaneous and dried fish (d) in Kaptai reservoir, Bangladesh, between 1965 and 2005.

Ordination of abundance time series by NMS converged into a two-dimensional solution (cumulative r^2 = 95.7%, axis 1 = 14.3%, axis 2 = 81.4%; final stress = 7.57, final instability = 0.0182, P = 0.0099). Strong positive correlations to axis 1 were found for abundance changes of dried fish (Kendall's tau = 0.69), air (tau = 0.43) and fali (tau = 0.41), whereas strong negative correlations were calculated for punti (tau = −0.46). Scores to axis 2 were positively correlated to kechki (tau = 0.72), tilapia (tau = 0.74) and bata (tau = 0.64), whereas negative correlations were found for mrigal (tau = −0.72), mahasoal (tau = −0.72) and catla (tau =

−0.69). The joint ordination plot indicated that the fish assemblage of Kaptai reservoir gradually changed by a slight decline of major carp species between 1965 and 1980 (Figure 4). However, between 1980 and 1986, the system experienced

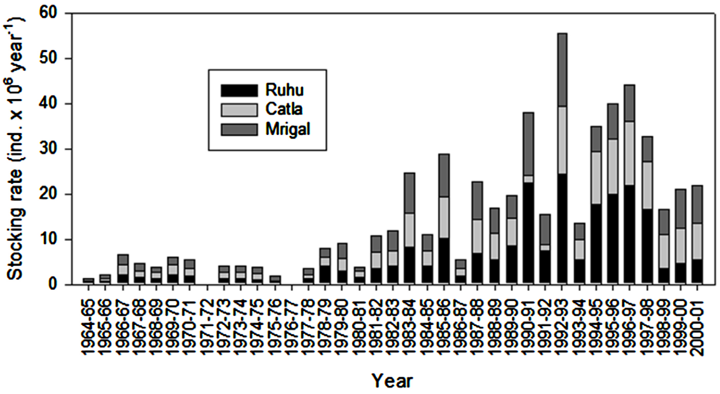

Figure 3. Annual supplemental stocking rates (ind. × 10^6 year^{-1}) of Indian major carps ruhu, catla and mrigal in Kaptai reservoir, Bangladesh.

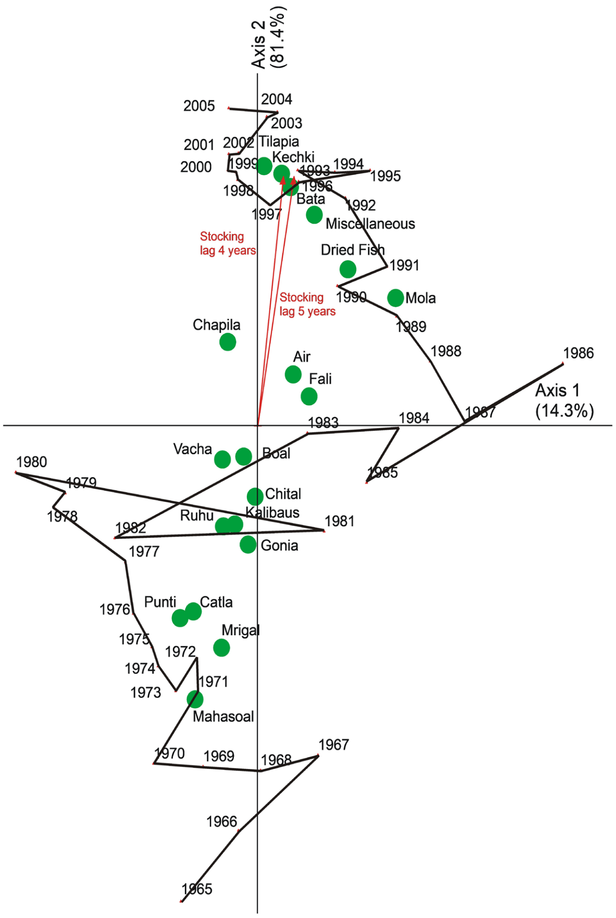

Figure 4. Joint ordination plot by nonmetric multidimensional scaling of time series of fisheries yield of 19 fish species in Kaptai reservoir, Bangladesh. The years are successively connected by a line to demonstrate succession. Vectors indicate the correlation of total annual stocking rates at time lags + 4 and + 5 years (Kendall's tau > 0.60).

radical jumps, indicated by large distances between the year-specific ordination scores. The highest differences of annual scores were observed between 1985 and 1986 (absolute difference of axis scores: axis 1: 0.63; axis 2: 0.66). From 1987 onwards, changes again became more gradual, but distances of ordinations scores to the original state in 1965 along axis 2 increased continuously such that the scores of 1965 and 2005 were placed at the opposite ends along axis 2 of the ordination diagram (Figure 4). Annual stocking of ruhu, catla and mrigal was positively correlated to both axis 1 and axis 2. The strongest correlations were found on axis 2 for total stocking (sum of ruhu, catla and mrigal) with a lag of four years (tau = 0.64) and a lag of five years (tau = 0.68, Figure 4).

Water level varied between 64 m above sea level (June 1985) and 109 m (November 1998), with the annual means being relatively stable over the 20 years period (1979 to 1998) except for extraordinarily low levels observed in 1985 (Figure 5(a)). Linear correlations between annual mean water levels and annual differences in ordination scores (Figure 4) were weak for both ordination axes without considering time lags. However, at a time lag + 1 year, low annual water levels caused the strongest shifts in fish assemblages in the subsequent year, as indicated by a significantly negative correlation between water level and the difference of annual ordination scores for ordination axis 2 (Pearson's r = −0.47, n = 20, P = 0.036; Figure 5(b)).

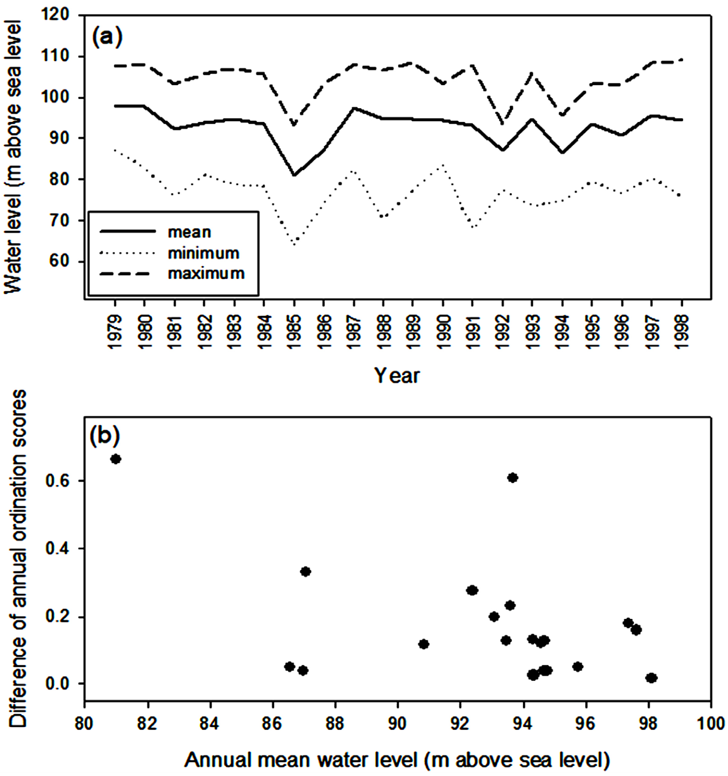

Figure 5. Mean, minimum and maximum water level (m above sea level) in Kaptai Lake between 1979 and 1998 (a), and scatter plot between annual mean water level and difference of subsequent year scores from axis 2 of ordination by nonmetric dimensional scaling with a time lag of +1 year (b).

4. Discussion

The long-term time series and ordination of annual fisheries yield and stocking in Kaptai reservoir indicate that the fish assemblage underwent a dramatic change within the recorded period of 41 years. Whereas the assemblage was dominated by major carp (mahasoal, mrigal, catla, ruhu) initially after impoundment, currently clupeids (kechki, chapila), minor carp (bata) and the dried and miscellaneous fish dominate the annual catches. The transition obviously has occurred rather quickly, with the most rapid changes being observed between 1980 and 1986. This rapid switch may be indicative of a regime shift. Furthermore, the continuous and intensified stocking of major carp species in particular since 1982 did not contribute to stabilizing the system at the desired state with major carp dominance. The strong positive correlation of stocking to the second ordination axis reveals that stocking may have rather accelerated the switch of the assemblage composition toward the current state.

The major carp are the most favored, commercially important fish in Bangladesh because of their price, taste and demand. Major carp dominated the fish assemblage of Kaptai reservoir in the early years after impoundment, as they contributed to about 81% of the total landings during the first harvest in 1965 - 1966. Over the following decades, their yield proportion steadily declined reaching about 1.1% currently. Due to this dramatic decline, one member of the major carp, mahasoal, is now treated as an endangered species.

The reasons for the decline may be related to overexploitation and impaired spawning by low water levels. The initial increase in the yield of major carp after impoundment was mainly attributable to the application of different fishing methods, but subsequently, the yield steadily declined [32]. Fisheries regulation was not successful in stopping the decline. Fishing in Kaptai reservoir remains closed from mid-June to mid-August. In some years, however, the start of this closure period is delayed to fulfill the fish harvesting targets set annually by BFDC, which unfortunately are not based on any factual data or scientific background [28]. Jenkins [40] concluded that the harvest of the major carp species might have exceeded the maximum sustainable level due to the setting of such targets. Accordingly, major carp stocks have been overexploited and fisheries have depleted the spawner stock biomass close to a threshold where natural recruitment is severely hampered since the 1980s (recruitment overfishing [41]). Current data on mean average length, body condition, length-weight relationship and maturity of major carp species indicate that these populations became stunted [33]. The mean catching sizes of ruhu, catla, mrigal and kalibaus were recorded as 41.3 ± 13.7, 54.5 ± 15.9, 38.2 ± 10.2 and 32.0 ± 19.6 cm, respectively in 1996 [42], but have declined to 36.6 ± 7.4, 40.4 ± 2.4, 31.1 ± 6.9 and 30.6 ± 6.3 cm, respectively in 1999 [33]. Accordingly, commercial catches of major carp are currently dominated by fish of poor body condition and a high percentage of undersized individuals.

A second reason for the decline of carp may be poor spawning due to water level fluctuations. Our analysis indicates that drastic changes in the fish assemblage occurred between 1982 and 1986; and the lowest water levels ever observed (1985/86) caused the most radical shifts in the ordination plot in the subsequent year (from season 1985/86 to 1986/87) thus pointing to the strong influence of water level on fish assemblage composition. For all major carp, spawning consists of two uneven seasonal pulses of which one occurs more or less in summer (April) and another during late monsoon (June) [43]. In Kaptai Lake, water level fluctuations represent the conflicting demands of hydropower generation and biological connectivity of the reservoir to spawning areas in the rivers. In particular, water level of the reservoir has been maintained at lower levels during the breeding seasons of major carp (Mid-June-Mid-August) do enhance the storage capacity at heavy rainfall. Accordingly, the fish start spawning only during the monsoon period when sudden heavy rainfalls provide both an environmental cue for mating and access to the upper reaches of the spawning rivers. The available historical data from Kaptai reservoir indicated the profound influence of reservoir water level on the annual difference in yield and the entire fish community [28] [44]-[46]. Although at the early stages of the reservoir after impoundment, natural spawning of major carp species was reported to have happened successfully, over time, siltation due to shifting cultivation practices in the surroundings, lack of rainfall and thunder showers at breeding time and low current velocity during the breeding season may have impaired breeding success more recently. Several attempts were made to explore the breeding grounds of major carp species in Kaptai reservoir, and four suspected spawning sites were identified during the mid-1980s [28] [29]. BFRI-RSS [47] suspected that sporadic spawning could happen in the suspected breeding grounds, but recruitment certainly has failed almost completely since the 1990s. In a similar way, fluctuations of water level and heavy shoreline siltation were identified as one of the major causes of the gradual disappearance of fish species and destruction of natural breeding grounds in the Lewis and Clarke Lakes in USA [48].

At present, the most dominant fish species in Kaptai reservoir are marine-derived Clupeid. Currently, they account for ≈75% of the total catch (kechki 42%, chapila 33%), with further increasing tendency. Whereas, the yield of kechki has been fairly stable over the 18-year period, chapila catches fluctuated more strongly. The switch of the system to short-lived pelagic species is typical for older low-productivity reservoirs exhibiting strong water level fluctuations [8]. A similar switch has been observed in Ubolratna reservoir (Thailand), where an explosive growth of Clupeidae (*Corica goniognatus*) was documented between the first observation in 1974 and the current proportion of ≈25% of the total catch [49]. At the same time, another pelagic species (*Corica jullieni*) also played a major role in the fish production of the same reservoir, contributing ≈24 - 36% of the total catch since 1976. Both species also recently appeared in other large reservoirs *viz.* Sirikit, Sirinthorn and Lampao, contributing 18.4, 52.4 and 62.3% of the total fish catch respectively [50]. Fernando and Holick [51] and Fernando [52] noted that, in addition to lacustrine fish, marine-derived fish, e.g. Clupeids, Osmerids and some other families, had colonized many reservoirs in the recent years. Petrere [53] showed that marine-derived species dominate in large reservoirs in South America.

To replenish the stocks of major carp and to mitigate the effects of possible breeding failures in the new impoundment, fingerlings of major carp have been stocked in Kaptai reservoir since the beginning of the fishery. Fishing at Kaptai reservoir was banned for the first three years (1962 - 1965) after its construction, and 2.3 million major carp fries were stocked for the first time to build up a readily available population. Since then, BFDC has released a substantial number of fingerlings almost every year, but without any signs of success. From 1990 onwards, a massive stocking program using 9 - 13 cm long fingerlings with a given species composition has been implemented. However, major carp stocks did not recover. Several reasons may explain the failure of the stocking program. First, fingerlings are produced 200 km away from the reservoir, and then have to be transported to the stocking location with little time for acclimatization, causing injury and infection. Second, there is evidence of an inbreeding effect since the parental stocks remained the same over the years [54]. Also, the use of fishing gear such as hooks and lines and brush shelters (fish aggregation device) catch a significant proportion of fingerlings during the post-stocking period [55]. Finally, the number of fish stocked may causes retarded growth and impaired recruitment due to food competition both between stocked juvenile carp and the currently dominating clupeids which are all primarily planktivorous [56]. Accordingly, the amount of money invested into stocking so far certainly exceeds the value of the recaptured fish in Kaptai reservoir, but BFDC has not yet undertaken any initiative to evaluate the success and cost-benefit ratio of this stocking programme.

Similarly, carp stocking in reservoirs has not been cost effective in Thailand [57], and has been a complete failure in Sri Lanka [58]. After 50 years, Sugunan [59] acknowledged that the stocking strategy in most Indian reservoirs by using Indian major carps (IMC) has failed. In Bhavanisagar, Tungabhadra, Krishnagiri, Malampuzha, Peechi and Nagarjunasagar reservoirs, stocked IMC fingerlings have had little impact on subsequent catches, as none of the stocked fish were reported to breed and contribute to self-recruitment. Sreenivasan [60] reviewed the impact of stocking in 10 reservoirs of Tamil Nadu. Stocked catla was found to build up a naturalized population in the Mettur reservoir, but this fishery suffered from periodic setbacks because of breeding failures. Stocking has been much more effective in improving the yield in small reservoirs, because the success of management depends more on directly recaptured fish from stockings than in the establishment of a self-recruiting population.

5. Conclusions and Recommendations

Since reservoirs are created artificially by flooding a particular habitat, environmental alterations during the maturation process are inevitable. After about 20 years, a "regime shift" has occurred in Kaptai reservoir from the dominance of riverine species (such as major carp) to marine-derived small pelagic species (such as clupeid). Many factors were identified that might be responsible for such dramatic switching *viz.* the recruitment overfishing, loss of natural breeding grounds due to low water levels during breeding seasons, failures of stocking programs, setting of unrealistic harvesting targets and the extent of potential competition between the native, invasive and exotic species. Nevertheless, apart from these natural, anthropogenic and irreversible causes, other main obstacles to improving the production potential of the reservoir are the ineffectiveness of implementing existing fishing regulations and prioritizing needs and the lack of the legislative policy framework for protection and conservation of aquatic resources.

In the future, effective implementation of existing fishing regulations, such as licensing, mesh size, legal catch size, approved gear, and fishing ban period must be ensured. This can be achieved by a major overhaul in defining the roles and responsibilities of key agencies (BFDC, BFRI, DoF and the Civil Administration) under a common policy framework. To protect the brood stock, fishing ban periods should start in early May and should be effectively implemented. Spawning stocks in migration channels are to be protected, and breeding performance is assured. A strong interagency coordination between BFDC, BFRI, DoF and KHPS is required to keep the water at the optimum level during the spawning season. A tripartite coordination between three main agencies, BFDC, BFRI and DoF could initiate the production of self-sustained fingerlings within or along the reservoir area, thereby avoiding the transportation of fingerlings over long distances. The involvement of local fishers during fishing ban periods in raising stocking materials may create an avenue by which to establish a congenial environment for the success of the supplemental stocking program. Nursing spawn in the creek/cove environment of the reservoir might be an excellent way of raising fingerlings within the reservoir environment, which could reduce the fingerling procurement costs of BFDC, as well as mortality. Management should also be aware of the inbreeding effect that results from artificial stocking. At least 20% of fingerlings should ideally come from natural sources, which points towards the need to develop natural spawning grounds upstream of the reservoir. BFDC’s target-oriented production plan should be avoided. Also, gear approval is essential. On the basis of known stock, fishing licenses from different gear should be issued for particular stocks. Fish sanctuaries should be declared, and year-round fishing should be restricted around each known spawning and nursery ground. Above all, an integrated approach to reservoir management is essential to improve the productivity of the reservoir based on scientific evidence and factual data. Considering the aforementioned issues, the Lake-based Riverine Sub-station of BFRI can actively collaborate with BFDC to address the biological and genetic challenges related to the lake. This could involve implementing various strategies for the biological management of the lake.

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Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Lluch-Belda, D., Lluch-Cota, D.B., Hernández-Vázquez and Salinas-Zavala, C.A. (1992) Sardine Population Expansion in Eastern Boundary Systems of the Pacific Ocean as Related to Sea Surface Temperature. *South African Journal of Marine Science*, **12**, 147-155. https://doi.org/10.2989/02577619209504698

[2] Scheffer, M., Carpenter, S., Foley, J.A., Folke, C. and Walker, B. (2001) Catastrophic Shifts in Ecosystems. *Nature*, **413**, 591-596. https://doi.org/10.1038/35098000

[3] Carpenter, S.R. (2003) Regime Shifts in Lake Ecosystems: Pattern and Variation. International Ecology Institute.

[4] Jeppesen, E., Søndergaard, M., Pedersen, A.R., Jürgens, K., Strzelczak, A., Lauridsen, T.L., *et al.* (2007) Salinity Induced Regime Shift in Shallow Brackish Lagoons. *Ecosystems*, **10**, 48-58. https://doi.org/10.1007/s10021-006-9007-6

[5] Minobe, S. (2000) Spatio-Temporal Structure of the Pentadecadal Variability over the North Pacific. *Progress in Oceanography*, **47**, 381-408. https://doi.org/10.1016/s0079-6611(00)00042-2

[6] Kawasaki, T. (2002) Climate Change, Regime Shift and Stock Management. *Fisheries science*, **68**, 148-153. https://doi.org/10.2331/fishsci.68.sup1_148

[7] Peterson, W.T. and Schwing, F.B. (2003) A New Climate Regime in Northeast Pacific Ecosystems. *Geophysical Research Letters*, **30**, Article No. 1896. https://doi.org/10.1029/2003gl017528

[8] Collie, J.S., Richardson, K. and Steele, J.H. (2004) Regime Shifts: Can Ecological Theory Illuminate the Mechanisms? *Progress in Oceanography*, **60**, 281-302. https://doi.org/10.1016/j.pocean.2004.02.013

[9] Kasai, H. and Ono, T. (2007) Has the 1998 Regime Shift Also Occurred in the Oceanographic Conditions and Lower Trophic Ecosystem of the Oyashio Region? *Journal of Oceanography*, **63**, 661-669. https://doi.org/10.1007/s10872-007-0058-x

[10] Francis, R.C., Hare, S.R., Hollowed, A.B. and Wooster, W.S. (1998) Effects of Interdecadal Climate Variability on the Oceanic Ecosystems of the NE Pacific. *Fisheries Oceanography*, **7**, 1-21. https://doi.org/10.1046/j.1365-2419.1998.00052.x

[11] McFarlane, G.A., King, J.R. and Beamish, R.J. (2000) Have There Been Recent Changes in Climate? Ask the Fish. *Progress in Oceanography*, **47**, 147-169. https://doi.org/10.1016/s0079-6611(00)00034-3

[12] Clark, W.G. and Hare, S.R. (2002) Effects of Climate and Stock Size on Recruitment and Growth of Pacific Halibut. *North American Journal of Fisheries Management*,

22, 852-862.
https://doi.org/10.1577/1548-8675(2002)022<0852:eocass>2.0.co;2

[13] King, J. (2005) Coherent Regional Responses. In: King, J.R., Ed., *Report of the Study Group on Fisheries and Ecosystem Responses to Recent Regime Shifts*, PICES Scientific Report No. 28, North Pacific Marine Organization (PICES), 37-50.

[14] Holliday, N. (2001) Is There a Connection between High Transport of Water through the Rockall Trough and Ecological Changes in the North Sea? *ICES Journal of Marine Science*, **58**, 270-274. https://doi.org/10.1006/jmsc.2000.1008

[15] Omori, M. and Kawasaki, T. (1995) Scrutinizing the Cycles of Worldwide Fluctuations in the Sardine and Herring Populations by Means of Singular Spectrum Analysis. *Bulletin of Japanese Society for Fisheries and Oceanography*, **59**, 361-370.

[16] Sakurai, Y. (2000) Changes in Inferred Spawning Areas of *Todarodes pacificus* (Cephalopoda: Ommastrephidae) Due to Changing Environmental Conditions. *ICES Journal of Marine Science*, **57**, 24-30. https://doi.org/10.1006/jmsc.2000.0667

[17] Tian, Y., Akamine, T. and Suda, M. (2002) Long-Term Variability in the Abundance of Pacific Saury in the Northwestern Pacific Ocean and Climate Changes during the Last Century. *Bulletin of Japanese Society of Fisheries and Oceanography*, **66**, 16-25.

[18] Yatsu, A. (2002) Monitoring of Pelagic Fish Resources in the Area around Japan. *Kaiyo Monthly*, **34**, 799-802. (In Japanese)

[19] Worm, B. and Myers, R.A. (2003) Meta-Analysis of COD-Shrimp Interactions Reveals Top-Down Control in Oceanic Food Webs. *Ecology*, **84**, 162-173.
https://doi.org/10.1890/0012-9658(2003)084[0162:maocsi]2.0.co;2

[20] Bundy, A. (2005) Structure and Functioning of the Eastern Scotian Shelf Ecosystem before and after the Collapse of Groundfish Stocks in the Early 1990s. *Canadian Journal of Fisheries and Aquatic Sciences*, **62**, 1453-1473.
https://doi.org/10.1139/f05-085

[21] Frank, K.T., Petrie, B., Choi, J.S. and Leggett, W.C. (2005) Trophic Cascades in a Formerly Cod-Dominated Ecosystem. *Science*, **308**, 1621-1623.
https://doi.org/10.1126/science.1113075

[22] Jackson, J.B.C., Kirby, M.X., Berger, W.H., Bjorndal, K.A., Botsford, L.W., Bourque, B.J., *et al.* (2001) Historical Overfishing and the Recent Collapse of Coastal Ecosystems. *Science*, **293**, 629-637. https://doi.org/10.1126/science.1059199

[23] Savenkoff, C., Castonguay, M., Chabot, D., Hammill, M.O., Bourdages, H. and Morissette, L. (2007) Changes in the Northern Gulf of St. Lawrence Ecosystem Estimated by Inverse Modelling: Evidence of a Fishery-Induced Regime Shift? *Estuarine, Coastal and Shelf Science*, **73**, 711-724.
https://doi.org/10.1016/j.ecss.2007.03.011

[24] Welcomme, R.L. (2001) Inland Fisheries: Ecology and Management. Blackwell, 358 p.

[25] Ahmed, K.K.U., Haldar, G.C., Saha, S.B. and Paul, S.K. (1994) Studies on the Primary Production in Kaptai Reservoir. *Bangladesh Journal of Zoology*, **22**, 69-77.

[26] Hye, M.A. and Alamgir, M. (1992) Investigation on the Natural Spawning of Carps in Lake Kaptai. *Bangladesh Journal of Zoology*, **20**, 27-33.

[27] Haldar, G.C., Mazid, M.A. and Ahmed, K.K. (1992) Limnology and Primary Production of Kaptai Lake, Bangladesh. *Reservoir Fisheries in Asia. Proceedings of the 2nd Asian Reservoir Fisheries Workshop*, Hangzhou, 15-19 October 1990, 2-11.

[28] Aquatic Research Group (ARG) (1986) Hydrobiology of the Kaptai Reservoir. University of Chittagong, FAO/UNDP Final Report No. DP/BGD/79/015/FI, 192.

[29] Azadi, M.A. (1985) Hydrological Conditions Influencing the Spawning of Major Carps in the Halda River, Chittagong, Bangladesh. *Bangladesh Journal of Zoology*, **13**, 163-172.

[30] Chowdhury, S.C. and Mazumdar, A. (1981) Limnology of Lake Kaptai-1: Physico-chemical Features. *Bangladesh Journal of Zoology*, **9**, 59-72.

[31] Haldar, G.C., Ahmed, K.K.U., Alamgir, M., Akhter, J.N. and Rahman, M.K. (2000) Chapter 12. Fish and Fisheries of Kaptai Reservoir, Bangladesh. In: Cowx, I.G., Ed., *Management and Ecology of Lake and Reservoir Fisheries*, Fishing News Books, Blackwell Science, 145-158.

[32] Ahmed, K.K.U., Hambrey, J.B. and Rahman, S. (2001) Trends in Interannual Yield Variation of Reservoir Fisheries in Bangladesh, with Special Reference to Indian Major Carps. *Lakes & Reservoirs*: *Science*, *Policy and Management for Sustainable Use*, **6**, 85-94. https://doi.org/10.1046/j.1440-1770.2001.00134.x

[33] Ahmed, K.K.U. and Hambrey, J.B. (2005) Studies on the Fish Catch Efficiency of Different Types of Fishing Gear in Kaptai Reservoir, Bangladesh. *Lakes & Reservoirs*: *Science*, *Policy and Management for Sustainable Use*, **10**, 221-234. https://doi.org/10.1111/j.1440-1770.2005.00280.x

[34] Ahmed, K.K.U., Rahman, S. and Ahammed, S.U. (2006) Managing Fisheries Resources in Kaptai Reservoir, Bangladesh. *Outlook on Agriculture*, **35**, 281-289. https://doi.org/10.5367/000000006779398281

[35] Ali, L. (1985) Proceedings of the National Conference on Fisheries Development in Bangladesh. 15-19, January 1985. Sponsored by Fisheries and Livestock Division. Ministry of Agriculture, 41.

[36] Ahmed, K.K.U. (1999) Options for the Management of Major Carp Fishery in the Kaptai Reservoir, Bangladesh. Ph.D. Dissertation, School of Environment, Re-sources and Development, Asian Institute of Technology, i-xxiii+298 p.

[37] BFRI-RSS (1993) Population Dynamics and Stock Assessment Studies on Kaptai Lake. Annual Progress Report (1991-1992), BFRI-RSS.

[38] Andersen, T., Carstensen, J., Hernández-García, E. and Duarte, C.M. (2009) Ecological Thresholds and Regime Shifts: Approaches to Identification. *Trends in Ecology & Evolution*, **24**, 49-57. https://doi.org/10.1016/j.tree.2008.07.014

[39] McCune, B. and Mefford, M.J. (1999) PC-ORD. Multivariate Analysis of Ecological Data, Version 4. MjM Software Design.

[40] Jenkins, R.M. (1985) Final Report on the Planning, Implementation and Follow-Up Activities Associated with the Survey of Fishery Management of Kaptai Lake Conducted by the Aquatic Research Group. University of Chittagong, 7.

[41] Gulland, J.A. (1983) Fish Stock Assessment: A Manual of Basic Methods. John Wiley and Sons Ltd., 223.

[42] Ahmed, K.K.U. and Saha, S.B. (1996) Length-Weight Relationships of Major Carps in Kaptai Lake, Bangladesh. NAGA, ICLARM Quarterly April, 28.

[43] Dewan, S. (2000) Stock Assessment and Population Dynamics of Commercially Important Fishes in Kaptai Lake. Consultancy Report on Population Dynamics. BFRI & BARC, Agricultural Research Management Project (ARMP) Technical Assistance, Winrock International, 32-72.

[44] Welcomme, R.L. (1970) Studies on the Effects of Abnormally High Water Levels on the Ecology of Fish in Certain Shallow Regions of Lake Victoria. *Journal of Zoology*, **160**, 405-436. https://doi.org/10.1111/j.1469-7998.1970.tb03090.x

[45] Silva, S.S.D. (1985) Observations on the Abundance of the Exotic Cichlid *Sarotherodon*

mossambicus (Peters) in Relation to Fluctuations in the Water-Level in a Man-Made Lake in Sri Lanka. *Aquaculture Research*, **16**, 265-272. https://doi.org/10.1111/j.1365-2109.1985.tb00315.x

[46] Jhingran, A.G. (1992) Recent Advances in Reservoir Fisheires Management in India. *Reservoir Fisheries of Asia*, *Proceedings of the* 2*nd Asian Reservoir Fisheries Workshop*, Hangzhou, 15-19 October 1990, 158-175.

[47] BFRI-RSS (2000) Studies of Production Potentiality and Management of Fisheries of Kaptai Lake. Annual Progress Report (1999-2000), BFRI-RSS.

[48] Walburg, C.H. (1976) Changes in the Fish Population of Lews and Clark Lake, 1956-1974, and Their Relation to Water Management and the Environment. U.S. Fish and Wildlife Service, Research Report, 79 p.

[49] Pawaputanon, O. (1986) Fisheries and Fishery Management of Large Reservoirs in Thailand. In: Maclean, J.L., Dizon, L.B. and Hosillos, L.V., Eds., *The First Asian Fisheries Forum*, Asian Fisheries Society, 389-392.

[50] Duangsawasdi, M. (1992) Post-Impoundment Studies on Aquatic Ecology and Fisheries in Bhumibol and Sirikit Reservoirs, Thailand. *Reservoir Fisheries of Asia*: *Proceedings of the* 2*nd Asian Reservoir Fisheries Workshop*, Hangzhou, 15-19 October 1990, 104-110.

[51] Fernando, C.H. and Holčík, J. (1991) Fish in Reservoirs. *Internationale Revue der gesamten Hydrobiologie und Hydrographie*, **76**, 149-167. https://doi.org/10.1002/iroh.19910760202

[52] Fernando, C.H. (1998) Lacustrine Fishes and Their Role in Asian Reservoirs. Department of Biology, University of Waterloo, 26.

[53] Petrere, M. (1996) Fisheries in Large Tropical Reservoirs in South America. *Lakes & Reservoirs*: *Science*, *Policy and Management for Sustainable Use*, **2**, 111-133. https://doi.org/10.1111/j.1440-1770.1996.tb00054.x

[54] Ahmed, K.K.U., Alamgir, M. and Haldar, G.C. (2002) Pen Fish Culture in Lake-Valley as a New Production System of Kaptai Reservoir, Bangladesh. In: Islam, Z., Ed., *Proceedings of the* 2*nd ANR Agricultural Conference*, ICMH, 20-126.

[55] Ahmed, K.K.U. and Hambrey, J.B. (1999) Brush Shelter: A Recently Introduced Fishing Method in the Kaptai Reservoir Fisheries in Bangladesh. *NAGA ICLARM Quarterly*, **22**, 20-23.

[56] Sandercock, F.K. (1966) Chittagong Hill Tracts Soil and Land Use Survey, Volume 4: Fisheries (Canadian Colombo Plan Project F-475). East Pakistan Agricultural Development Corporation.

[57] Bhukaswan, T. and Chookajorn, T. (1988) Reservoir Fisheries Management in Thailand. *Reservoir Fishery Management and Development in Asia*, *Proceedings of a workshop*, Kathmandu, 23-28 November 1987, 154-157.

[58] Fernando, C.H. (1993) Impact of Sri Lankan Reservoirs, Their Fisheries, Management and Conservation. In: Erdelen, W., Preu, C., Ishwaran, N. and Madduma Bandara, C.M., Eds., *Ecology and Landscape Management in Sri Lanka*, Margraf Scientific Books, 351-367.

[59] Sugunan, V.V. (1997) Fisheries Management of Small Water Bodies in Seven Countries in Africa, Asia and Latin America. FAO Fisheries, Circular 933, 148.

[60] Sreenivasan, A. (1984) Influence of Stocking on Fish Production in Reservoirs of India. *Fisheries Chimes*, **13**, 18-21.