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Comparative study of food webs from two different time periods of Hooghly Matla estuarine system, India through network analysis

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ABSTRACT

Two mass-balanced network models of Hooghly Matla estuarine system, from two different time periods (less exploited phase → 1985–1990 and highly exploited phase → 1998–2003) have been constructed for quantitative comparison. The models are used to estimate the important biological interactions and relationships among different ecologically important groups. 20 functional groups based on species of different habitats from coastal areas in this ecosystem have been identified, including shrimps, squids, crabs, mackerel, small pelagics, demersal fishes, benthic feeders, predator fishes and trash fish. The biomass values for these components are estimated from catch production and bottom trawling surveys. The values of Ecotrophic Efficiency in the models are high (>0.5) for most groups of higher trophic levels. Interactions among different components are clearly understood from the outputs of models with a focus on energy flow. Most fish population are observed to approach high degree of exploitation with change in the overall trophic structure mainly due to top down effects. Several system statistics and network flow indices from the model outputs indicate that this estuary is facing degradation and stress resulting in some degrees of instability.

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1. Introduction

The Hooghly Matla estuarine ecosystem with adjacent mangroves is one of the largest detritus based ecosystems of the world (Pillay, 1958) and has great importance in costal landscape of India. Estuarine system are of interest because the most sensitive land-water-atmosphere interactions are pronounced at these region. It provides diverse habitat for wide variety of aquatic resources of ecological and economic significance including finfish, prawn, bivalve, gastropod, fiddler crab and plankton etc. (Mitra et al., 2000, 1997; Nath et al., 2004). Beside this, like other estuaries, the Hooghly Matla system also has great significance as it supports many essential fisheries of high economic value.

But recent years have seen this ecosystem to have degraded gradually owing to the different anthropogenic factors such as overfishing, development of agriculture and sewage from aquaculture farms, expansion of human settlements (900 km^{-2}; 2001 census), establishment of Farakka barrage in the upper stream of river, construction of Kolkata-Haldia ports and climatic factors like rise in temperature, sea level, salinity and increasing frequency of severe cyclones such as Nargis, Bijli and Aila in recent years (Hazra et al., 2010, 2002). These hamper the ecological balance affecting the food web of the concerned system (Islam, 2013) .The increasing trend of fish yield over years (from 27014.5 t in 1984–93 to 64204.3 t in 1999–2003) has resulted into a drastic decline in the fish catch per unit effort (CPUE) from 189.7 kg in 1990–91 to 44 kg in 2002–03 (Mitra et al., 1997; Nath et al., 2004; Sinha, 2004). Technically this is termed as overfishing; a form of overexploitation where the amount of fish caught reduces the population below the level at which fish population can naturally sustain itself. This may happen in water bodies of any sizes from small ponds and rivers to oceans and can result in resource depletion, reduced biological growth rates, low biomass level in fish population. Futhermore, it can lead to critical situations where fish population are no longer

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able to sustain themselves and may become extinct. For example, species like *Lisa tade, Lates calcarifer* have declined and *Tenualosa toli, Chanos chanos* are totally absent in recent years (Mitra et al., 2000; Sinha, 2004). Not only that, but these situations may lead to impacts including alternation of species diversity of other trophic level, declination of mean trophic level within the system and significant habitat modification or destruction. Beside this, it affects the social and economic wellbeing of the coastal communities who depend on fish for their way of life.

Overfishing has significantly affected many fisheries around the world. As much as 85% of world's fisheries are estimated to be depleted, overexploited, fully exploited or in recovery from exploitation. For example, areas like Northeast Atlantic, the Western Indian Ocean and the Northwest Pacific ocean are in fully exploited condition (UNFAO, 2012 Statistical Year Book; UNFAO, General facts regarding world fisheries). It is a warning signal for the future of a sustainable ecosystem. Therefore, impacts of perturbations on the trophic structure of this ecosystem should be examined in order to form proper scientific management policies related to fishery and other modes of resource utilization; otherwise the system may collapse at some point in the future. Overfishing will be detrimental to the fishery industries as well as biodiversity of this system. In order to ensure sustainable and scientific fisheries management, a more holistic approach that balances both human well-being and ecological well-being are required. Modern aquatic resource management is based not only on monospecific approach but on an ecosystem approach as it includes fish as well as different organisms and different natural processes. In this regard, static mass balanced modelling approach, well-grounded with realistic data, can give answers to many salient questions for analysing ecosystem structure and function holistically. Following the comparative analysis of trophic networks between virgin and reclaimed island by Ray and Straškraba (2001) and Ray (2008), the goal of the work presented in this paper was to characterize the Hooghly Matla estuarine complex in terms of mass balanced models to obtain holistic view of the same. This study emphasized two key questions: (1) is the system gradually degrading due to overexploitation and (2) if the case is so, then how much has it degraded over years and how much is the system under stress?

To answer these questions, we constructed two mass balanced trophic network models of Hooghly estuary using Ecopath with Ecosim (EwE) software (Christensen et al., 2005) for different phases. The first model pertaining to a less exploited phase (**phase 1,** 1985–1990), and the second focused on the more exploited time phase (**phase 2,** 1998–2003). This work has three specific objectives: (1) to understand different trophic interactions (2) identification of the different pathways of energy transfer (3) investigating the current status of ecosystem efficiency in order to point the major pathway controlling the food web of this ecosystem.

2. Materials and methods

2.1. Study area

The Hooghly Matla estuarine ecosystem (HMES) is situated 21° 32′ N and 22° 40′ N; 88° 05′ E and 89° E, at an altitude 0–10 m above sea level and just south of Kolkata. It houses the estuarine phase of the River Ganges and measures 9630 km^2, out of which 4262 km^2 is intertidal area. A large saline water zone of 1892 km^2 has been selected as the current study area; this selection is done in accordance to previous study of Ganguly et al. (2006). Average surface water temperatures (27.3 °C and 28.7 °C) are obtained from (Nandy et al., 1983) and (Biswas et al., 2004) respectively for the two different phases. Maximum catches are recorded (90%) from remote places of the lower estuary, including some fishing centres such as Diamond Harbour, Kakdwip, Namkhana, Bokkhali, Jambudwip, Frasergung and Sagar Island (Mitra et al., 2000). The two time-periods under consideration are the less exploited, **phase 1** (1985–1990) and the highly exploited, **phase 2** (1998–2003). Both of the time periods are used while constructing two models for the system as the best records are available for those years (Fig. 1).

2.2. Network modelling approach

Widely used static modelling software Ecopath with Ecosim (EwE) version 6.5 (Christensen et al., 2005; Coll et al., 2009) was applied to construct the mass balanced models (a snapshot, in terms of trophic flows and biomasses at precise time periods) providing static and quantitative descriptions of studied ecosystem. It derives model parameters on the basis of two master equations, one of which ensures the balance of energy over each compartment: consumption (***Q***) = production (***P***) + respiration (***R***) + unassimilated food (***U***); and the other one describes the production term that is balanced by predation mortality, fishing mortality and other mortality due to old age.

$$P_i = Y_i + B_i M2_i + E_i + BA_i + P_i(1 - EE_i)$$

$$Or\ B_i * \left(\frac{P}{B}\right)_i * EE_i - \sum_{j=1}^{n} B_j * \left(\frac{Q}{B}\right)_j * DC_{ji} - Y_i - E_i - BA_i = 0$$

where, B_i is the biomass of prey (***i***); $\left(\frac{P}{B}\right)_i$ is the production to biomass ratio of prey (***i***); $M2_i$ is total predation mortality rate for prey (***i***) by predator (***j***), summation term $B_i M2_i$ signifies total predatory losses of prey (***i***) to all predators (***j***), that is equal to $\sum_{j=1}^{n} B_j * \left(\frac{Q}{B}\right)_j * DC_{ji}$ where B_j is the biomass of predator (***j***); $\left(\frac{Q}{B}\right)_j$ is the consumption to biomass ratio of predator (***j***); DC_{ji} is the fraction o prey (***i***) by weight in the average diet of predator (***j***); Y_i is the catch due to fishing, EE_i is the ecotrophic efficiency of (***i***) which is the proportion of the production that it is used within the system due to consumption or is exported from the system by fishing. Assumptions were taken that there was no biomass accumulation (BA_i) and net migration (E_i) from this system.

2.3. Functional groups and attributes

Two mass balanced EwE network models for two different time periods provide comparative and quantitative descriptions of the interactions in the trophic structure of the ecosystem. To define functional groups in the ecosystem it is necessary to identify ecologically similar species and group them together (Coll et al., 2009) in order to simplify the models. For this reason, the models though initiated with over 50 species – associated with 27 commercially important fish and several other non-fish species – are narrowed to 20 groups during the literature review process to reduce the complexity. A few species of lesser importance or with unavailable data are excluded. The EwE master equation contains four core parameters that describe the basic biology of each functional group: biomass (***B***), production to biomass ratio (***P/B***), consumption to biomass ratio (***Q/B***) and ecotrophic efficiency (***EE***). The biomass values of all functional groups are calculated in terms of carbon currency. Three out of these four parameters for each functional group are gathered from data source and are used as input in the initial model framework. Beside this, to run EwE model, the diet matrix was conceptualized and created. It describes the trophic interlinking between different functional groups and dependency of the components upon each other of this ecosystem.

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