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Sustainable exploitation of hilsa fish (*Tenualosa ilisha*) population in Bangladesh: Modeling and policy implications

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ABSTRACT

This paper presents a computer model of hilsa fish (*Tenualosa ilisha*) to predict the long-term trends in the hilsa population over several decades and to assess the impacts of harvesting the juveniles and spawning adults of hilsa fish. The model is designed to keep track of the population in various phases of the life cycle. The computer model of hilsa fish is based on system dynamics methodology. The full history of the cause and effect relationships of the population dynamics of hilsa fish is presented using causal loop and flow diagrams. STELLA software is used to model the population dynamics of hilsa fish and the parameters of the model are estimated from field data and reports. Maximum sustainable yield and carrying capacity were simulated to be 268,000 tons and 670,000 tons, respectively. The overall situation of hilsa fishery is under severe stress in Bangladesh and vulnerable to over exploitation. Simulation results show that increased harvesting of the adults entering the rivers and the juveniles in the rivers cause gradual decline in hilsa fish population and even may cause to disappear this valuable resource within a short period of time. Also the optimal strategies for sustainable development of hilsa fishery have been addressed and the optimization results show that optimized operation of the hilsa fishery not only stabilizes the system, but also enhances the harvested adult hilsa. The model has the potential to analyze the harvesting strategies of the adults entering the rivers and juveniles in the rivers for sustainable exploitation of the hilsa fish.

1. Introduction

Hilsa (*Tenualosa ilisha*) is the national fish of Bangladesh. It is the largest single species fishery in Bangladesh especially during the monsoon and contributes about 22–25% of the total fish production of the country. Average annual production of hilsa is 200,000 tons and its value is TK 20,000 million (1 US Dollar = Taka 70.00). The contribution of this fish in the GDP of Bangladesh is 1% and annually Taka 500–600 million is earned as foreign currency from the export of hilsa. It is harvested mainly by gill net and about 2% of the total population of Bangladesh is directly or indirectly involved in this fishery.

Hilsa fish is one of the popular food items in the diet of the people in Bangladesh. The food value of this fish is rich enough. Proteins, minerals, unsaturated fat (2% omega-3 fatty acid) and vitamins-A, D and B are available from this fish. The taste and flavors of this fish are fully dependent on its fat contents.

Total catch of hilsa in Bangladesh ranged between 194,981 and 280,328 tons with an average of 217,681 tons per year from 1987 to 2007 and the total production increased approximately 48% during this period (Mome and Arnason, 2007). Also the hilsa catch in 2011 in Bangladesh was 313,753 tons (BBS, 2012). In the year 2003, the estimated standing stock size and MSY (maximum sustainable yield) were 218,000 tons and 235,000 tons, respectively (DOF, 2005). This indicates the over-fishing of the hilsa stock existed earlier.

There is a decline of fisheries worldwide due to overexploitations of the stocks (FAO, 1995) and there is also a decrease of about 19% in harvesting of hilsa in the recent years. If this trend continues, the existence of this fish will be at risk and eventually it will become a rare species.

The sustainable management of marine renewable resources requires integration of biological, economic and social aspects (Nunes et al., 2004; Bald et al., 2009). Considering the importance

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of hilsa fisheries in nutrition, diet, employment and economy, the sustainable management of hilsa fishery is very important. For sustainable production of hilsa fish as well as increase in production sound development policy and management strategies are urgently needed.

Several studies have been reported on modeling of population dynamics of fish (Tian et al., 2004; Robadue and Simanek, 2007) and other species such as gooseneck barnacle (Bald et al., 2006). Few studies have been reported on the contributions of overfishing on the decline/collapse of the fish stock (Lillegard et al., 2005; Kaitala et al., 2003; Jonzen et al., 2001). Limited studies have been reported on parameters such as mortality, catch rate, and maximum sustainable yield of hilsa using FISAT software (Miah et al., 1997; Amin et al., 2000; Haldar and Amin, 2005; Hashemi et al., 2010). Mome and Arnason (2007) reported a simple bio-economic model similar to the FISAT software and it is not a true model, rather is a supplementary model.

The purpose of this study is to develop a system dynamics simulation model of population dynamics of hilsa fish to assess the policy options and management strategies for sustainable development of hilsa fish. To understand and model the population dynamics of hilsa fish a knowledge of the reproduction system of hilsa fish is essential. To bridge this gap we present a brief and comprehensive description of the reproduction system of hilsa fish relevant to system dynamics modeling of population dynamics of hilsa fish. Then we focus on the system dynamics modeling of hilsa fish population and examine the harvesting policies of juveniles and spawning adults and the policies for sustainable exploitation of hilsa fish. Finally we present policy implications for sustainable exploitation of hilsa fish and the conclusion of this research.

2. Reproduction system of hilsa

There are five species of hilsa under *Tenualosa* order found in the world. The two species, *Tenualosa ilisha* and *Tenualosa toti* are found in Bangladesh. The availability of hilsa is 50–60% in Bangladesh, 20–25% in Myanmar and 10–15% in India and rest 5–10% in all over the world.

The species of hilsa is heterosexual and the females due to faster growth rate attain larger sizes than the males. Shafi et al. (1977a,b) observed that the body of females is broader and the girth is comparatively larger. Opinions differ whether one sex predominates over the other in different phases of the life history of hilsa or whether the distribution conforms to the normal 1:1 ratio. Quereshi (1968) observed that although the sex ratio was 1 during the monsoon, the females dominated in October.

There is some evidence to suggest that there are two different and distinct spawning stocks or varieties. Quddus (1983) reported that the stocks responsible for the two spawnings are different – the 'broad' variety taking part in monsoon spawning and the 'slender' variety in the winter spawning. Comparative studies by Quddus (1982) of the 'broad' and 'slender' types of hilsa indicate a highly significant difference between the two types in the fecundity estimates. In the 'broad' type, the fecundity estimates range from 0.6 to 1.5 million for the fish in the size range of 33–51 cm, and for the 'slender' type from 0.4 to 0.6 million for fish ranging in size from 32 to 49 cm. Hatching takes place in about 23–26 h at an average temperature of 23 °C (Jones and Menon, 1951); 18–26 h at 28.0–28.5 °C (Kulkarni, 1950); and at about 24–28 h (Motwani et al., 1957). The length of the newly hatched larvae is recorded as 2.3 mm by Jones and Menon (1951); 3.1 mm by Kulkarni (1950); 2.50–2.55 mm by Motwani et al. (1957); and 2.4–3.0 mm by Karamchandani (1961).

The juveniles remain in the rivers/estuaries till they probably reach a length of 150–160 mm which is believed to be attained in about five months time. It is possible that the seaward migration is undertaken at this size/age. It has been reported that the operation of small-mesh nets in the period immediately succeeding the breeding season results in large-scale destruction of young fish in Bangladesh waters (Quereshi, 1968).

Conflicting views have been expressed on the minimum size of hilsa at first maturity. Hilsa may attain first maturity at the end of the first year, or at the beginning of the second year. In Bangladesh waters (Meghna), Shafi et al. (1978) observed a size of 21 cm in the case of males and 32 cm in the case of females, as the size at first maturity.

Hilsa is essentially a plankton feeder and generally, the items which are preponderant are crustaceans (particularly copepods), diatoms, green and blue algae; organic detritus, mud and sand have also been recorded. Pillay (1958) has reported that no evidence of cessation or appreciable decrease in the feeding activity during the spawning period, but some workers reported that during spawning migration the intensity of feeding decreases or ceases altogether (Pillay and Rosa, 1963).

To model the various phases of the life cycle of hilsa fish the information on the reproduction system such as sex ratio, eggs per nest, larva, juvenile and maturation of hilsa fish from different sources have been carefully examined and incorporated in the model to make it to represent the real world situations of the hilsa fish in Bangladesh.

3. Modeling of hilsa fish population dynamics

The dynamic behavior of a physical system can be studied by experimentation of the system itself or by experimentation with the prototypes of the physical system. However, full-scale experimentations for physical systems are sometimes time consuming and costly, and even may not feasible. But computer model is the most inexpensive and less time consuming method (Bala, 1999).

Modeling of hilsa fish is a highly complex and such modeling analyses require that effects on the population dynamics of feedback mechanisms within population as well as natural variation in environment are properly modeled. System dynamics methodology is the most appropriate techniques to analyze the dynamic behavior of such a complex dynamic system. Since systems dynamics is a methodology of constructing computer models based on feedback concept and it is well suited to physical, agricultural, aquacultural, environmental and socio-economic systems (Bala, 1999).

Again, some software programs and packages have now become available that offer dynamic modeling capabilities and sophisticated graphics interfaces. STELLA an icon oriented software developed by High Performance Systems has revolutionized the system dynamics modeling process and allow to model virtually any process. Thus, STELLA enhances understanding of biological, social and physical systems.

Dynamic systems consist of interconnected feedback loops and the feedback loops simulate dynamic behavior of the systems. In system dynamics modeling causal loop diagrams identify the principal feedback loops of a system and the causal loop diagram is used to describe the basic cause–effect relationships hypothesized to generate the reference mode of the behavior over time (Sterman, 2000). The causal loop diagram of the population dynamics model of hilsa fish is shown in Fig. 1. The population dynamics model of hilsa fish is dominated by one positive and four negative loops. The positive loop shows the reproductive and maturation process, ultimately producing more adult hilsa. The number of spawning adults of hilsa fish will determine the number of larvae production and leads to the production of matured adults of hilsa fish. Juvenile rate, prematuration rate, maturation rate and spawning rate have positive effect on the production of hilsa fish. In the absence of any stabilizing, this loop would result in the exponential growth of the