
Modelling of Hilsa Fish (*Tenualosa ilisha*) Population in Bangladesh

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In the previous chapter, the modelling and simulation of boom and bust of cocoa production systems in Malaysia have been presented. This chapter demonstrates how to construct a system dynamics model of hilsa fish and simulate the model for policy planning and design for sustainable development. The model presented in this chapter is organised as follows: (1) introduction, (2) dynamic hypothesis, (3) causal loop diagram, (4) stock–flow diagram, (5) model validation, (6) simulation and policy analysis and (7) conclusion to illustrate the system dynamics applications based on systems thinking. Such experiences are essential to face the challenge of modelling and simulation of dynamic systems. The model predicts the long-term trends in the hilsa population over several decades and assesses the impacts of harvesting the juveniles and spawning adults. Simulated 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 this valuable resource to disappear within a short period of time. Also the optimal strategies for sustainable development of hilsa fish have been addressed.

9.1 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. The 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.

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 of hilsa fish 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 modelling 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). 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 bioeconomic model similar to FISAT software, and it is not a true model; rather, it is a supplementary model.

The system dynamics simulation model of population dynamics of hilsa fish presented here to assess the policy options and management strategies for sustainable development of hilsa fish is adopted from Bala et al. (2014). 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 modelling of population dynamics of hilsa fish. Then we focus on the system dynamics modelling of hilsa fish population and examine the harvesting policies of juveniles and spawning adults and the policies for sustainable exploitation of hilsa fish.

There are five species of hilsa under *Tenualosa* genus found in the world. The two species, *Tenualosa ilisha* and *Tenualosa toli* are found in Bangladesh. The availability of hilsa is 50–60 % in Bangladesh, 20–25 % in Myanmar and 10–15 % in India and the rest 5–10 % 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), about 18–26 h at 28.0 °C to 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 5 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 a 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 and green and blue algae; organic detritus, mud and sand have also been recorded. Pillay (1958) has reported 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 has been carefully examined and incorporated in the model to make it to represent the real-world situations of the hilsa fish in Bangladesh.

9.2 Dynamic Hypothesis

The dynamic hypothesis is a conceptual model, and it hypothesises to define the critical feedback loops to construct stock–flow diagrams that drive the system’s behaviour in the reference mode. When the model is simulated, the endogenous structure of the model generates the reference mode behaviour of the system, and thus, the endogenous structure causes the changes in dynamic behaviour of the system. In system dynamics modelling, causal loop diagrams identify the principal feedback loops of a system, and the stock–flow diagrams that describe the structure of the systems are hypothesised to generate the reference mode of the behaviour over time (Sterman 2000). Hilsa population can be represented by causal loop diagrams and stock–flow diagrams, and the simulation model based on the causal loop diagrams and stock–flow diagrams would generate the dynamic behaviour of

the hilsa population. The population dynamics of hilsa in the form of causal loop diagrams and stock–flow diagrams are hypothesised to generate the observed hilsa population dynamics in the reference mode. In essence the decline in hilsa population results from the overharvesting of juveniles and spawning adults, and this dynamics results from the endogenous consequences of the feedback structure.

9.3 Causal Loop Diagram

The causal loop diagram of the population dynamics model of hilsa fish is shown in Fig. 9.1. 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 stabilisation, this loop would result in the exponential growth of the hilsa population. The negative feedback loops are balancing loops of the different stages of the life cycle of hilsa fish, and these are deaths of larvae, juvenile, premature adults and matured adults. An increase in the number of hilsa fish population at any stage of the life cycle will increase the number of deaths, and this in turn will decrease the number of hilsa population. Also harvesting at any stage of the life cycle of hilsa fish has a negative effect on the hilsa population. The negative loops cause the stabilisation at the different stages of the life of hilsa fish due to death and harvesting of the hilsa fish.

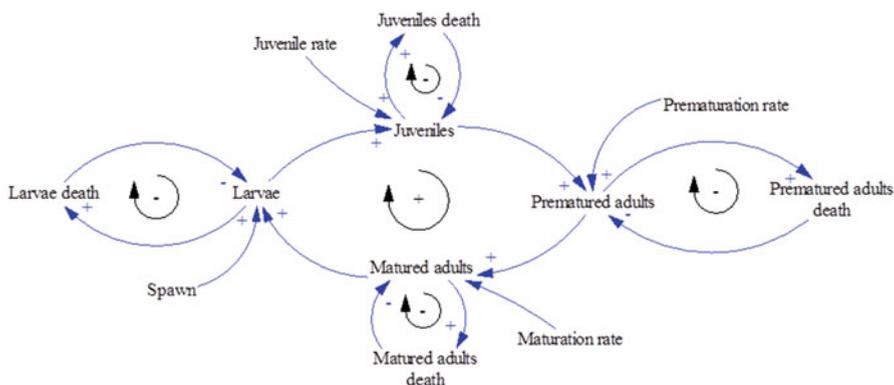


Fig. 9.1 Causal loop diagram of the population dynamics of hilsa fish

9.4 Stock–Flow Diagram

Figure 9.2 shows the stock–flow diagram of the population dynamics of hilsa fish. The flow diagram shows how stocks and flows are interconnected to produce the feedback loops and how the feedback loops interlink to create the system. The model is designed with seven stocks to keep track of the population of hilsa at the various phases of the life cycle is shown in Fig. 9.2. The life cycle begins when the adults of hilsa are about to spawn in rainy season during monsoon for laying eggs. The adults about to spawn in the rainy season for laying eggs can be described as:

$$\begin{aligned}
 \text{adults_about_to_spawn}(t) = & \text{adults_about_to_spawn}(t - dt) \\
 & + (\text{adults_leaving} - \text{adults_at_spawning} - \text{harvesting}) * dt
 \end{aligned}
 \tag{9.1}$$

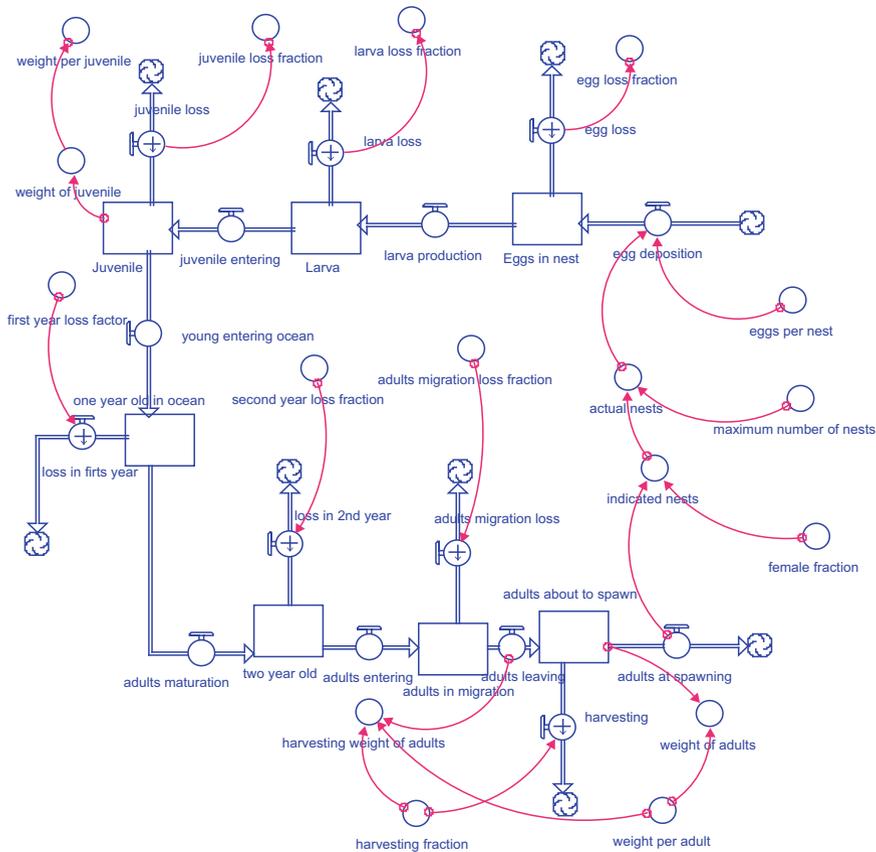


Fig. 9.2 Flow diagram of the population dynamics of hilsa fish

where $adults_about_to_spawn(t)$ is adults about to spawn at time (t) , $adults_leaving$ is the 2-year-old adults which have left sea and joined spawning at time $(t-dt)$, $adults_at_spawning$ is the adults which have started spawning at time $(t-dt)$ and $harvesting$ is harvesting rate of adults about to spawn at time $(t-dt)$.

The adults about to spawn lay eggs in the spawning grounds in the rivers and the eggs in the nest can be expressed as:

$$\begin{aligned} Eggs_in_nest(t) = & Eggs_in_nest(t - dt) \\ & + (egg_deposition - larva_production - egg_loss) * dt \end{aligned} \quad (9.2)$$

where $Eggs_in_nest(t)$ is eggs layed in the nest at time (t) , $egg_deposition$ is egg deposited in the nest at time $(t-dt)$, $larva_production$ is the larva produced from eggs at time $(t-dt)$ and egg_loss is egg lost in the nest at time $(t-dt)$.

These eggs hatch 1 month later and larvae are produced from the eggs. The production of larvae can be expressed as:

$$\begin{aligned} larva(t) = & larva(t - dt) \\ & + (larva_production - juvenile_entering - larva_loss) * dt \end{aligned} \quad (9.3)$$

where $larva(t)$ is larva at time (t) , $larva_production$ is the larva produced at time $(t-dt)$, $juvenile_entering$ is the juvenile emerged from larva at time $(t-dt)$ and $larva_loss$ is larva lost at time $(t-dt)$.

Larva takes 2 months to become juvenile. The juveniles are the recruiting phase of hilsa and the recruitment occurs more or less throughout the year with a major peak in June and July (Milton 2010). The juvenile population can be described as:

$$\begin{aligned} Juvenile(t) = & Juvenile(t - dt) \\ & + (juvenile_entering - young_entering_ocean \\ & - juvenile_loss) * dt \end{aligned} \quad (9.4)$$

where $Juvenile(t)$ is the Juvenile population at time (t) , $juvenile_entering$ is larva emerged into juvenile at time $(t-dt)$, $young_entering_ocean$ is the young juvenile leaving then river at time $(t-dt)$ and $juvenile_loss$ is the juvenile lost in the river at time $(t-dt)$.

The Juveniles remain in the rivers/estuaries for 8 months till they probably reach a length of 150–160 mm and then make the journey for sea. The 1-year-old in the ocean can be expressed as:

$$\begin{aligned} one_year_old_in_ocean(t) = & one_year_old_in_ocean(t - dt) \\ & + (young_entering_ocean - adults_maturation \\ & - loss_in_first_year) * dt \end{aligned} \quad (9.5)$$

where $one_year_old_in_ocean(t)$ is the 1-year-old hilsa in ocean at time (t) , $young_entering_ocean$ is the young hilsa entering in the ocean at time $(t-dt)$,

adults_maturation is the matured hilsa at time (t-dt) and loss_in_the_first_year is the hilsa lost in the first year in the sea at time (t-dt).

The juvenile that left the river develops maturity within 2 years in the sea and the 2-year-old matured hilsa in the sea can be described as:

$$\begin{aligned} \text{two_year_old}(t) = & \text{two_year_old}(t - dt) \\ & + (\text{adults_maturation} - \text{adults_entering} - \text{loss_in_2nd_year}) * dt \end{aligned} \tag{9.6}$$

where 2_year_old(t) is the 2-year-old hilsa in the sea at time (t), adults_maturation is the young 1-year-old hilsa maturing into 2-year-old hilsa in the ocean at time (t-dt), adults_entering is the 2-year-old hilsa leaving the sea and entering the rivers/estuaries at time (t-dt) and loss_in_2nd_year is the loss of 2-year-old hilsa in the sea at time (t-dt).

The adult fish (2-year-old) from the sea return to rivers/estuaries where they lay eggs and this category of 2-year-old adults in rivers/estuaries is described as:

$$\begin{aligned} \text{adults_in_migration}(t) = & \text{adults_in_migration}(t - dt) \\ & + (\text{adults_entering} - \text{adults_leaving} - \text{adults_migration_loss}) * dt \end{aligned} \tag{9.7}$$

where adults_in_migration(t) is 2-year-old adult hilsa migrating from sea to river at time t, adults_entering is the adults joining migration for journey to river at time (t-dt), adults_leaving is the adults left sea and entered the river at time (t-dt) and adults_migration_loss is the loss of adult hilsa during migration at time (t-dt).

Equations 9.1, 9.2, 9.3, 9.4, 9.5, 9.6, and 9.7 are solved using Runge–Kutta fourth-order method using STELLA software. The parameters of the model are estimated from studies, reports and publications. The parameters of the model are shown in Table 9.1.

In this part of modelling, we present a simple dynamic model for optimal harvesting strategy of adult hilsa for sustainable development of hilsa fishery using the population model. The optimisation problem is defined as the problem of maximisation of the total harvest of adult hilsa for the entire simulation period under conditions that the catch of adult hilsa fish is maintained at the maximum sustainable yield, i.e. spawning biomass is conserved and the harvesting juvenile is not allowed to exceed the present level of loss fraction of juvenile for sustainable harvest for all cycles of hilsa production. The objective function is to maximise the total adult harvested biomass during the whole year for sustainable development of hilsa fishery using the population model. The harvesting of adults of hilsa was optimised for sustainable development of hilsa fishery in Bangladesh. The model was simulated to:

Maximise

$$Z = \int_0^{T_i} HB(t) dt \tag{9.8}$$

Subject to the constraints

Table 9.1 Parameters used in the model

Parameter	Units	Adult		Egg	Larva	Juvenile	Mature
		M	F				
Average length*	mm	400	430	0.8	17.15	180	340
Average weight*	G	810	830	—	—	90	530
Female fraction****	Decimal	—	0.5	—	—	—	—
Eggs per ground**	Million	—	—	0.20	—	—	—
Stock*	Million	187.17	187.17	7,486,800	74,868	14973.6	898,42
Loss fraction***	Decimal	—	—	0.99	0.8	0.4	0.3
Stock after loss*	Million	37.43	37.43	74,868	14973.6	8984.2	628,89
Harvesting fraction***	Decimal	0.8	0.8	—	—	0.95	—
Second year loss fraction*	Decimal	—	—	—	—	—	0.5
Stock at second year*	Million	—	—	—	—	—	314,45

Sources: Mome and Amason* (2007), Milton** (2010), Amin et al*** (2000, 2002) and Halder and Amin**** (2005)

$$C_p = MSY$$

$$L_f \leq L_{fe}$$

$$0.0 \leq H_f \leq 1.0$$

$$\int_0^{T_{p1}} HB(t) dt = \int_0^{T_{p2}} HB(t) dt = \int_0^{T_{p3}} HB(t) dt = \dots$$

where $HB(t)$ is the harvested weight of adult hilsa at time (t) , tons/month; C_p the catch (yield), tons; MSY the maximum sustainable yield, tons; L_f the loss fraction of juvenile, decimal; L_{fe} the present loss fraction of juvenile, decimal; H_{fe} the harvesting fraction of adult hilsa, decimal; T_p the period of cycle, month; and T_t the total simulation period, month.

An adaptive pattern search was used for the solution of the constrained optimisation problem stated in Equation 9.8. This method does not require derivatives or approximation to derivatives to solve the problem, and it has been found to be very effective in solving non-linear constrained optimisation problems in system dynamics (Keloharju and Wolstenholme 1989; Dangerfield and Roberts 1996). The technique consists essentially of an exploratory search and a pattern search under constrained conditions.

9.5 Model Validation

The tests for building confidence in system dynamics models include (1) tests of structure, (2) tests for behaviour and (3) tests for policy implications (Bala 1999). Various ways of validating a system dynamics model have been considered such as comparing the model results with collected data; checking whether relations among the variables are logical and real, whether the model generates plausible behaviour and whether the model can generate anticipated behaviour under extreme condition; and checking the quality of parameter's value. Parameters have been derived from studies, other reports and publications to judge the plausibility of the model.

The behaviours of the key variables in the base run were examined. However, the management decisions have not been tested with time series field data since time series data are not available but have been compared with the reported values available. Forrester and Senge (1980) pointed out that for the public and political leaders, a useful model should explain causes of important problems and provide a basis for designing policies that can improve behaviour in the future. In the behaviour validity tests, emphasis should be on the behavioural patterns rather than on point prediction (Barlas 1996). The model presented generated plausible behaviours. An extreme condition test was conducted to check whether the model is capable to cope with extreme conditions and can provide the anticipated behaviour. One such extreme condition is the destruction of the spawning grounds, and it is anticipated that first juvenile and then adults should disappear within a very short

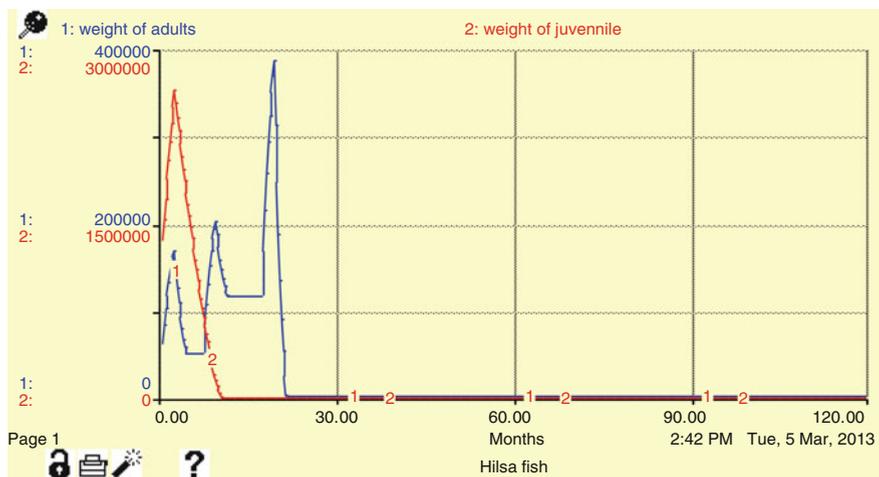


Fig. 9.3 Weights (tons) of adults about to spawn for total destruction of the habitats, i.e. eggs per nest = 0.0

time if the spawning grounds are destroyed. Figure 9.3 shows the simulated results for such a condition, and the simulated results show that first juvenile and then adults will disappear within 10 and 20 years, respectively. The model predictions are exactly what were anticipated.

The sensitivity of the important parameters was also estimated. In this study, behaviour sensitivity analysis of total weights of hilsa fish about to spawn to eggs per nest (150,000, 2,000,000 and 250,000) and adult migration loss (0.15, 0.25 and 0.35) was conducted. Figures 9.4 and 9.5 show the changes in total weights of adults for changes of eggs per nest (150,000, 2,000,000 and 250,000) and adult migration loss (0.15, 0.25 and 0.35), respectively. The total weights of adults increase with the increase of eggs per nests, while the total weights of adults decrease with the increase in values of adult migration loss, and these correspond with real-world situations.

The model is able to provide qualitative and quantitative understanding of the impacts of harvesting of juvenile and spawning adult hilsa fish, and the model represented the perceptions of reality and could be a good communication tool to advocate actions towards better management strategies of the harvesting of juvenile and spawning adult hilsa fish for sustainable exploitation of the hilsa fishery.

9.6 Simulation and Policy Analysis

System dynamics model is essentially developed to predict policy scenarios and applied to the understanding and modelling of complex systems. Because of the difficulty of documenting the effects of juvenile and adult hilsa fish, questions about

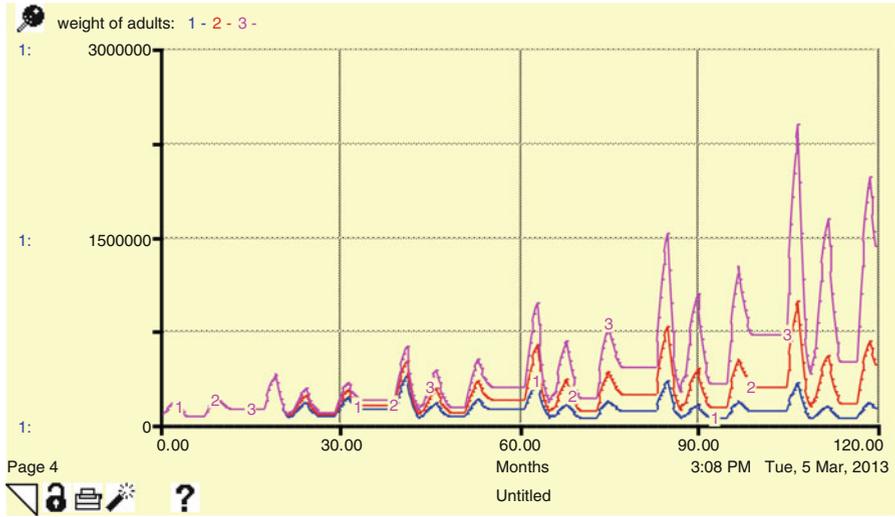


Fig. 9.4 Sensitivity analysis of the total weights of adults about to spawn to eggs per nest (150,000, 200,000 and 250,000)

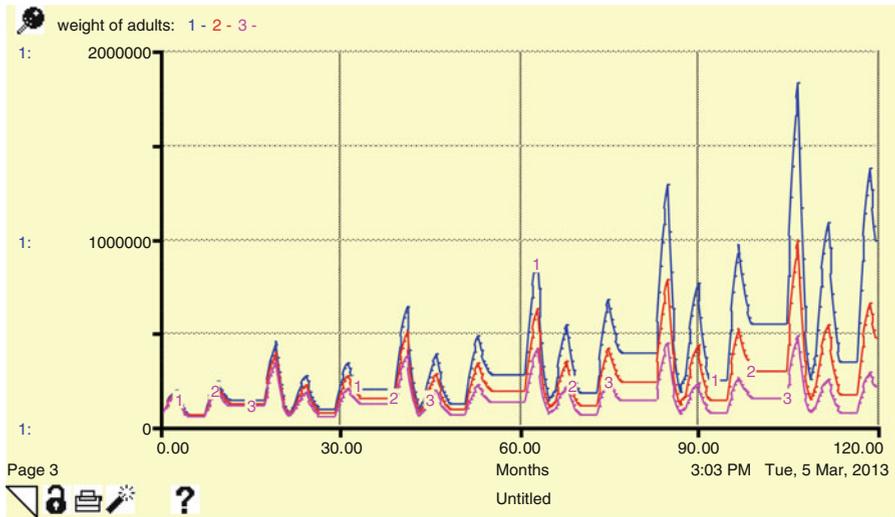


Fig. 9.5 Sensitivity analysis of the total weights of adults about to spawn to adult migration loss (0.15, 0.25 and 0.35)

the effectiveness of hilsa fishery management have been addressed through system dynamics model of hilsa fish population dynamics. In Bangladesh restricting the harvest of juvenile hilsa fish is extensively advocated for hilsa fishery management for sustainable development. This question is also addressed in this study. To examine the potentiality of the model as a tool for policy analysis, several policy options and management strategies are designed and tested. The policy options and management strategies are simulated for a time horizon of 10 years.

Scenario 1: Present practice of harvesting of juveniles and adults continued (base case)

This scenario is based on the information collected from different sources and updated to the present practices to assess the impacts of the harvesting of juveniles and adults of hilsa as usual in the coming years. Simulated weight and population of hilsa fish are shown in Figs. 9.6 and 9.7, respectively, and the time horizon is 10 years starting 2004. Figure 9.6 shows that the monthly changes in weights of adult and juvenile are stabilising with time for the juvenile loss fraction of 0.95 and harvesting loss fraction of 0.8. And also Fig. 9.7 shows that the monthly changes in population of 2-year-old fish, adults in migration, eggs in nest, juvenile and adults about to spawn are stabilising with time. The juvenile loss fraction and harvesting fraction include both the natural mortality and fishing mortality of juvenile population and adult hilsa fish population. The present harvesting practice does not result in any progressive decline of hilsa fish (Figs. 9.6 and 9.7). But in both cases, the growth rates of juveniles and adults about to spawn are very small. The monthly

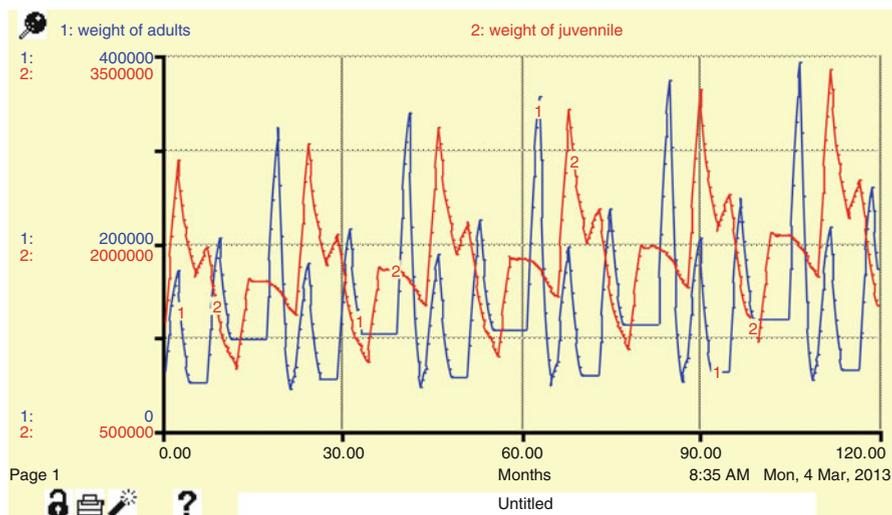


Fig. 9.6 Weights (tons) of juvenile and adult population of hilsa for the present practice of harvesting of juveniles and adults

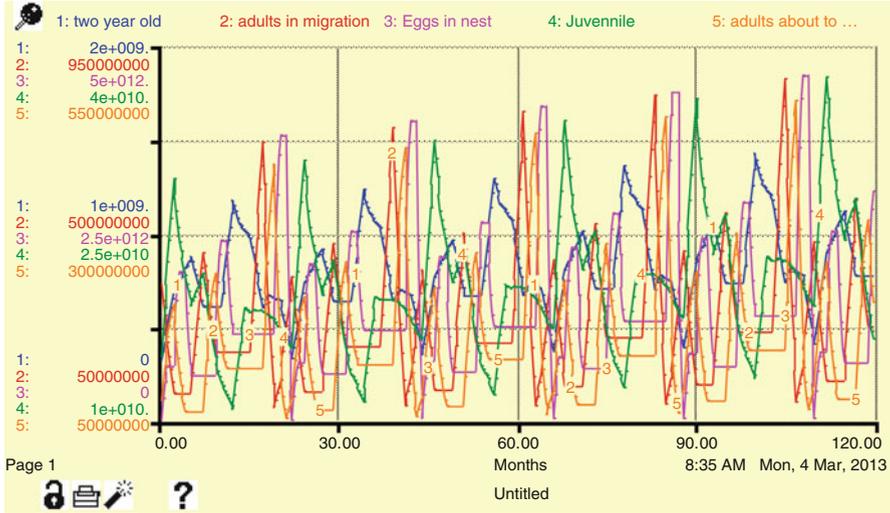


Fig. 9.7 Population of 2-year-old, adult in migration, egg and juvenile of hilsa for the present practice of harvesting of juveniles and adults

changes in the weights of adult hilsa of the standing stock during harvesting season in Fig. 9.6 show that the weights of standing stock of adult hilsa fish change from 290,000 to 3 80,000 tons which compare well with the reported value of 354,000 tons (Mome and Arnason 2007). The simulated results predicted the maximum sustainable yield to be 268, 000 tons. But Mome and Amarson (2007) reported that hilsa catch ranged between 194,981 and 280,328 tons from 1987 to 2007 and BBS (2012) reported a total catch of 313,753 tons of hilsa in Bangladesh which clearly indicates overfishing of hilsa in Bangladesh. Carrying capacity has been defined in many different ways, and it is not a constant number, and changes in environmental conditions may reduce the carrying capacity (Ayllon et al. 2012). The carrying capacity of hilsa fish was computed from the simulated results based on Gordon–Schaefer model (Siddique 2011), and it was found to be 670,000 tons. The monthly changes in the weights of juvenile hilsa during harvesting season also follow the patterns of the monthly changes in the weights of adult hilsa. The monthly changes in the population of 2-year-old, adult in migration, juvenile and egg of hilsa fish in Fig. 9.7 show similar patterns of changes with different magnitudes and time lags. No time series data are available to compare the simulated population dynamics of the hilsa fish.

Scenario 2: Harvesting mortality of juveniles is increased from 0.95 to 0.98

Scenario 2 is designed to assess the impacts of increasing the harvested amounts of juveniles, i.e. 3 % increase in harvesting mortality on the standing stock of hilsa in the future years. Figures 9.8 and 9.9 show the impacts of 3 % increase in harvesting mortality of the juvenile on the standing stock of hilsa in the future

years. Figure 9.8 shows that the weights of adult hilsa fish during harvesting season decrease from 153,000 to 75,000 tons within 30 months. Figure 9.8 also shows that the weights of adult and juvenile are decreasing rapidly, and it will be almost zero after 90 months of simulation time. Figure 9.9 shows that the population of 2-year-old fish, adults in migration, eggs in nest, juvenile and adult about to spawn are

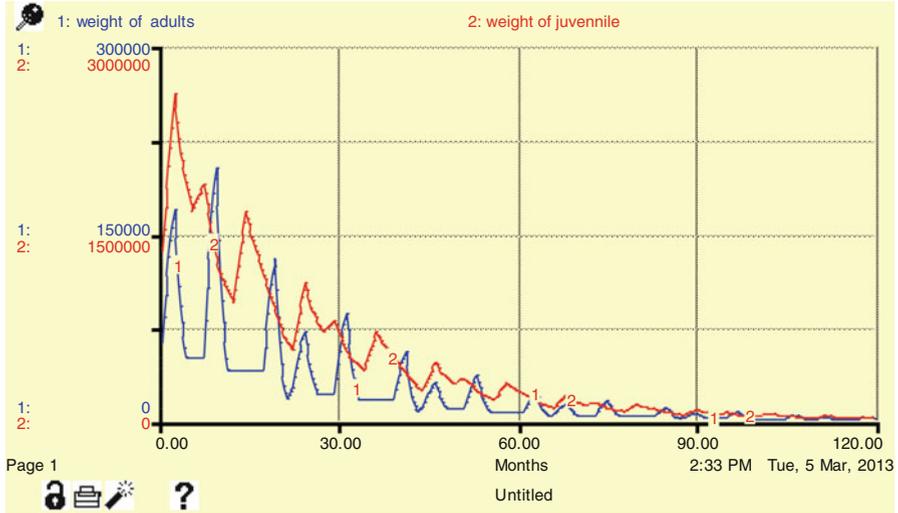


Fig. 9.8 Weights (tons) of juvenile and adult population of hilsa for the increase in harvesting mortality of juveniles from 0.95 to 0.98

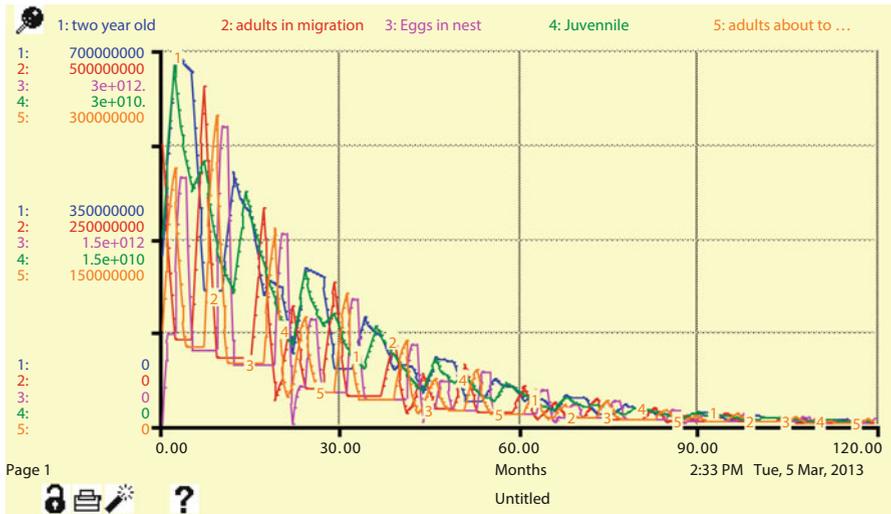


Fig. 9.9 Population of 2-year-old, adult in migration, egg and juvenile of hilsa for the increase in harvesting mortality of juveniles from 0.95 to 0.98

decreasing and ultimately become almost zero after 90 months of simulation time. Thus, increased juvenile harvesting has a negative impact on hilsa fish to disappear this valuable fish resource within a short period of time. This progressive decline of hilsa fish population for increased juvenile harvesting can be explained by the fact that the increased juvenile harvesting reduces the juvenile entering the ocean which ultimately reduces the adults in migration. This also reduces adults about to spawn and the larva production. As a result the juvenile population is further reduced resulting in progressive decline of hilsa fish population. Several researchers also reported similar findings (Amin et al. 2000; Halder and Amin 2005; Hashemi et al. 2010). Amin et al. (2000) also reported overfishing of juvenile of hilsa for a loss fraction of 0.948 which is within the range of loss fraction of the overfishing of juvenile of hilsa in this study. To stabilise the hilsa fishery system, the juvenile standing stock/population should not exceed the level presented in Scenario 1.

Scenario 3: Harvesting of adults about to spawn is increased from 0.80 to 0.95

Scenario 3 is designed to assess the impacts of increasing the harvested amounts of adult hilsa, i.e. 15 % increase in the harvesting mortality of adults on the standing stock of hilsa in the future years. The effects of increase of the harvesting loss fraction to 0.95 on hilsa fish population are shown Figs. 9.10 and 9.11 respectively. Figure 9.10 shows that the weights of adult hilsa fish during harvesting season decrease from 153,000 to 37,500 tons within 30 months. Figure 9.10 also shows that the weights of adult and juvenile are decreasing rapidly, i.e. the production of hilsa will decrease to almost zero within 60–70 months. Figure 9.11 also gives similar trends for 2-year-old, adults in migration, eggs in nest, juvenile and adults about to spawn. It also shows that the existence of hilsa will be at risk, i.e. it will be almost zero after 70 months. This progressive decline of hilsa fish population for increased adult harvesting can be explained by the fact that the increased adult harvesting reduces the adults about to spawn which ultimately reduces the larva production. This also reduces juvenile production and entering the ocean and the adults leaving migration. As a result, the adults about to spawn are further reduced resulting in progressive decline of hilsa fish population.

Thus, the simulated results show that for increasing harvesting fraction, i.e. harvesting mortality of adult about to spawn is more effective to cause disappear hilsa species within several years. To avoid such a collapse of hilsa fishery in Bangladesh, the harvesting strategies should be not to exceed the maximum sustainable yield. Halder and Amin (2005) also reported that fishes are harvested at a level than optimum fishing mortality and suggested some management policy to reduce the fishing mortality.

Scenario 4: Sustainable harvesting strategy of adults for the present juvenile loss fraction of 0.95

Scenario 4 is designed to develop sustainable harvesting strategy of the adults for the existing practices of overfishing of juvenile (0.95). For this policy, the

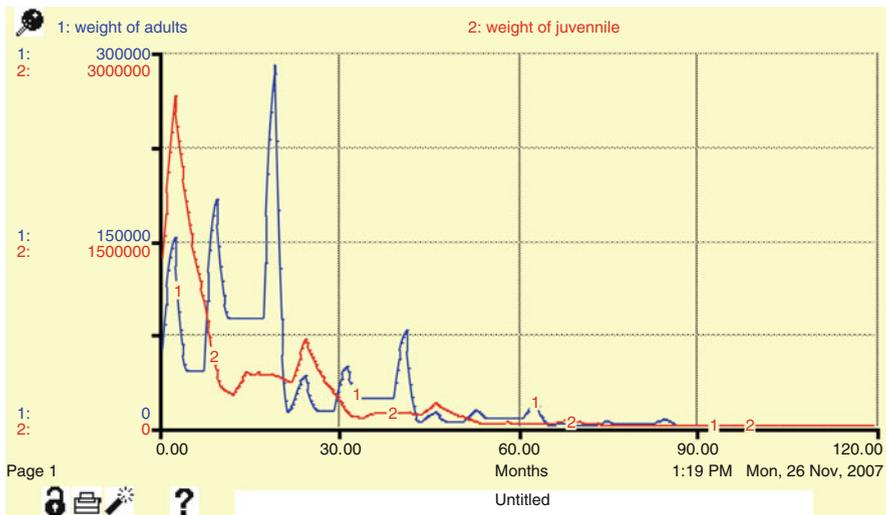


Fig. 9.10 Weights (tons) of juvenile and adult population of hilsa for the increase in harvesting mortality of adult from 0.80 to 0.95

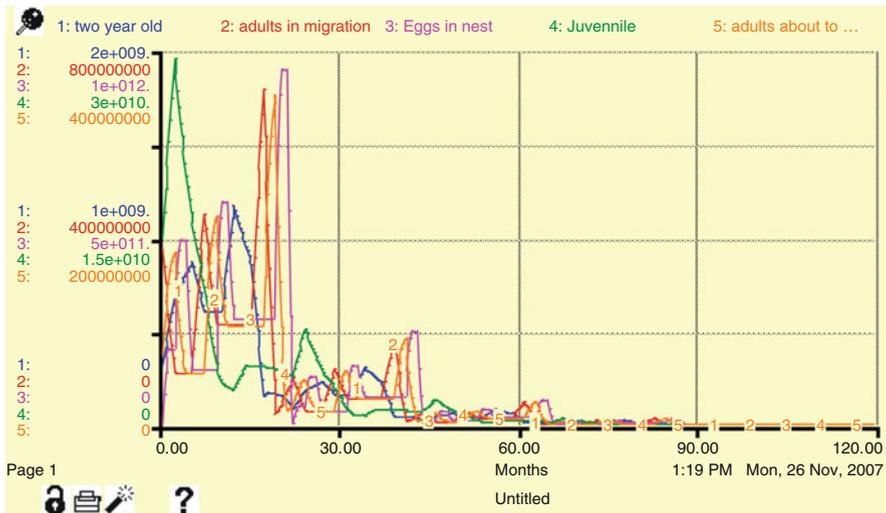


Fig. 9.11 Population of 2-year-old, adult in migration, egg and juvenile of hilsa for the increase in harvesting mortality of adult from 0.80 to 0.95

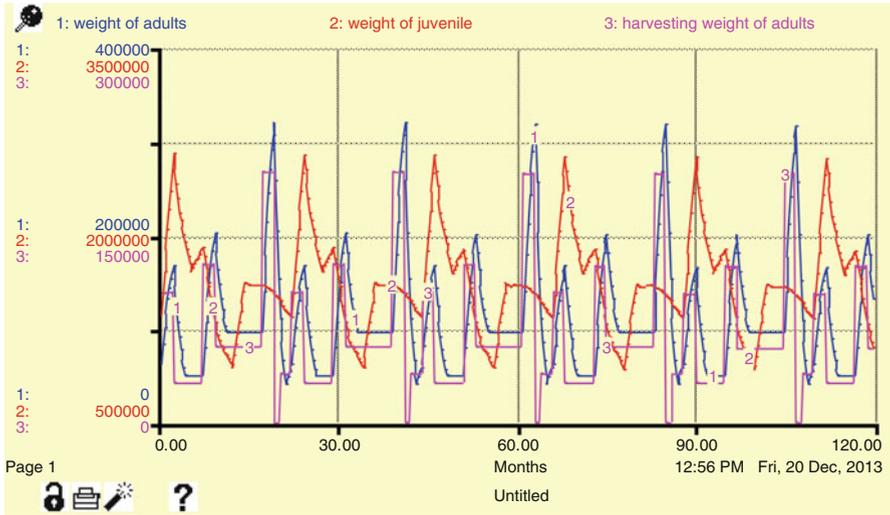


Fig. 9.12 Weights (tons) of juvenile, adult population and harvesting adults of hilsa for optimal harvesting of adult hilsa for the present loss fraction of the juveniles

restriction on maximum sustainable is relaxed. This policy considers proportional harvesting of the adults since this will ensure round-the-year fishing and hence livelihood of the fishermen. Figure 9.12 shows that simulated weights of the juvenile, adult hilsa and harvested adult hilsa for optimal harvesting strategy for sustainable development of hilsa fishery are stabilised. The optimal harvesting fraction of the adults for the existing juvenile harvesting practices of 0.95 was found to be 0.81 for sustainable development of the hilsa fishery. This will result in the stock of the adult hilsa in the peak season to be 320,137 tons and the highest peak season harvest of 200,821 tons.

Scenario 5: Sustainable harvesting strategy for sustainable development

Scenario 5 is designed to develop sustainable harvesting strategy of the adults and the reduction of the loss fraction of juvenile needed to maintain the carrying capacity of hilsa fishery. This policy also considers proportional harvesting of the adults since this will ensure round-the-year fishing and hence livelihood of the fishermen. Figure 9.13 shows that simulated weights of the juvenile, adult hilsa and harvested hilsa for sustainable development of hilsa fishery are stabilised. The optimal harvesting fraction of the adults and loss fraction of the juvenile harvesting fraction were found to be 0.85 and 0.935, respectively, for sustainable development of the hilsa fishery. This will cause to increase the stock of the adult hilsa and harvesting adults in the peak season 1.35 and 1.24 times higher than those of the previous policy (Scenario 4). Thus, this policy not only stabilises the hilsa fishery but also enhances the harvested adult hilsa and maintains the maximum sustainable yield.

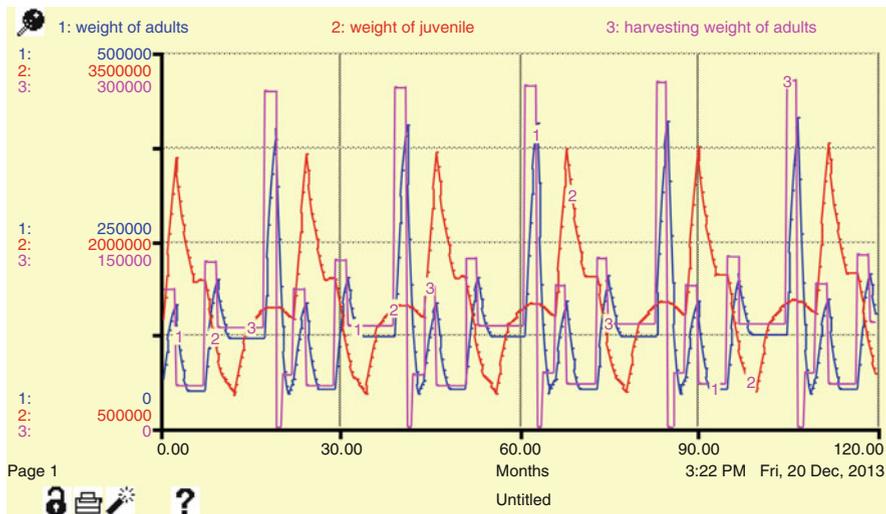


Fig. 9.13 Weights (tons) of juvenile and adult population of hilsa for optimal harvesting of adult hilsa for sustainable development of hilsa fishery

9.7 Conclusions

A computer model for hilsa fish population dynamics using system dynamics technique has been developed, and the model was simulated for the time horizon of 10 years. Two policy options such as juvenile harvesting mortality and increased level of harvesting of the adults are considered. Juvenile stage is the most critical stage for hilsa. Simulated results show that juvenile harvesting mortality and increased level of harvesting of the adults are the two sensitive policy issues for sustainable production of hilsa in Bangladesh. If appropriate policy options and management strategy for juvenile harvesting mortality and harvesting of the spawning adults are implemented, sustainable production of hilsa fish in Bangladesh could be maintained. Otherwise, this valuable resource of hilsa fish in Bangladesh will disappear within a short period of time. To address this problem, optimal harvesting strategy for sustainable hilsa fishery has been developed, and it not only enhances but also stabilises the hilsa fishery system. This model can be used to design policy options and management strategies for sustainable production of hilsa fish. However, further refinement of the model and updating of the data are needed.

Exercises

Exercise 9.1 Why is there a decline of fisheries worldwide? Discuss the importance of hilsa fishery in the context of economy and livelihood of hilsa fishing community in Bangladesh.

- Exercise 9.2** Draw the causal loop diagrams of hilsa fishery which includes local price of hilsa fish and livelihood of hilsa fishing community.
- Exercise 9.3** Draw stock–flow diagram of the causal loop diagram in exercise 9.2 and simulate hilsa production, local price of hilsa and livelihood of the hilsa fishing community.
- Exercise 9.4** What are the two main types of harvesting practices of hilsa population in Bangladesh which are common scenario? Discuss the relative importance and trade-off for sustainable development.
- Exercise 9.5** Discuss what should be the sustainable harvesting strategy for sustainable development. How can this be implemented using participatory systems approach?

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