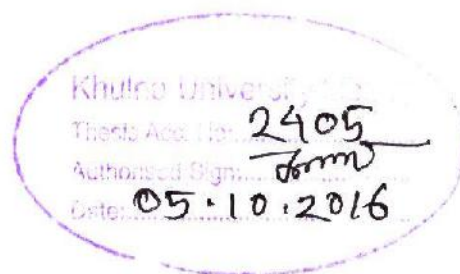


**GUESSTIMATION OF THE MAXIMUM SUSTAINABLE YIELD
FOR THE PASUR RIVER FISHERY IN KHULNA REGION BY
USING SURPLUS PRODUCTION MODEL**



A Thesis By



Md. Hafizur Rahman

Examination Roll No: MS-140619

Session: 2013-2014



The Thesis submitted to the Fisheries and Marine Resource Technology Discipline in
partial fulfillment of the requirements for the degree of

Master of Science in Fish Processing & Quality Control

Khulna University

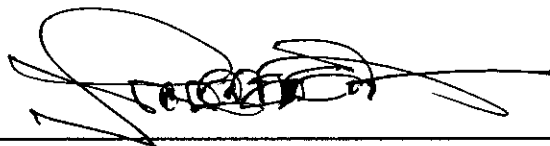
Khulna, Bangladesh

November, 2015

**GUESSTIMATION OF THE MAXIMUM SUSTAINABLE YIELD
FOR THE PASUR RIVER FISHERY IN KHULNA REGION BY
USING SURPLUS PRODUCTION MODEL**

Approved as to style and content

By



Professor Dr. Md. Ayaz Hasan Chisty

Head

Fisheries and Marine Resource Technology Discipline

Life Science School, Khulna University

Khulna-9208, Bangladesh

DECLARATION
GUESSTIMATION OF THE MAXIMUM SUSTAINABLE YIELD FOR
THE PASUR RIVER FISHERY IN KHULNA REGION BY USING
SURPLUS PRODUCTION MODEL

The results presented in the thesis with the above mentioned title are the candidate's own investigations and no part of the results has been accepted for any degree nor is it being concurrently submitted for any degree.

Candidate

Md. Hafizur Rahman

(Signature of the Candidate)

Md. Hafizur Rahman

Examination Roll No: **MS-140619**

Session: 2013-2014

Co-supervisor

 18.02.16

(Signature of the Co-supervisor)

Md. Moshir Rahman, PhD

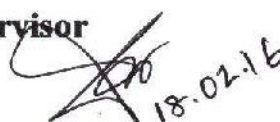
Associate Professor

Fisheries and Marine Resource Technology Discipline

Khulna University, Khulna-9208, Bangladesh



Supervisor

 18.02.16

(Signature of the Supervisor)

Muhammad Abdur Rouf, Ph.D.

Professor

Fisheries and Marine Resource Technology Discipline

Khulna University, Khulna-9208, Bangladesh

November, 2015

Dedicated to
My Beloved parents

Acknowledgement

At first, all my admiration goes to the supreme creator and Ruler of the universe, the Almighty God, for his great mercy to keep me alive and enables me to pursue my education in Fisheries and Marine Resource Technology Discipline as well as to complete my thesis for the degree of Master of Science in Fisheries.

I wish to express my sincere thanks to Department of fisheries, for providing me with necessary secondary data and guidelines to complete this thesis.

I would like to express my sincere gratitude and profound appreciation to my supervisor, **Muhammad Abdur Rouf, Ph.D., Professor**, Fisheries and Marine Resource Technology Discipline, Khulna University, Khulna for his continuous guidance, valuable suggestions and sustained support in preparing this thesis.

I would like to express my deepest sense of gratitude and profound respect to Professor Dr. Md. Ayaz Hasan Chisty, Head of Fisheries and Marine Resource Technology Discipline, Khulna University, Khulna for his valuable suggestions and providence of all necessary facilities.

I am grateful and deeply thankful to Bidhan Chandro Mondol, for his cordial co-operation and providing different types of catch data to complete this thesis.

I would like to express my co-supervisor Md. Moshir Rahman, Associate Professor, Fisheries and Marine Resource Technology Discipline, for his guidance to complete my thesis.

Finally, I would like to express my earnest appreciation to my parents, for their immeasurable blessing, continuous inspiration and financial support throughout the study.

Md. Hafizur Rahman

November, 2015

Abstract

Maximum sustainable yield (MSY) was estimated for the two major groups of fishery (inland fish and small shrimp) of the Pasur River based on four years (from 2011 to 2014) fishery dependent data of catch and effort records following the unit of effort as 200m² SBN/day from the Department of Fisheries. Surplus production model (Fox model) was used to estimate the MSY. Sustainable yield of approximately 4.61 kg of fish taken by 13.51 units effort of inland fish and 4.46 kg of fish taken by 9.48 units effort of small shrimp. The obtained MSY were smaller than the recent catch which indicates that this fishery was overexploited and require some effective management and should maintain sustainable exploitation of the stocks by reducing fishing effort in the area. The relationship between the estimated and observed Catch per unit effort (CPUE), Ratio of estimated yield (C_t) and MSY (C_t/MSY) and Ratio of estimated fishing effort (f_t) and f_{msy} (f_t/f_{msy}) for inland fish and small shrimp were estimated by deterministic approach and it suggested that there were overfishing in few months of January, February, March, June, July and December for inland fish and February, March, June, October and December for small shrimp. Furthermore, the mean of MSY and total allowable catch (TAC) with 95% Confidence interval (CI) for inland fish were 4.53 (4.52-4.54) kg and 4.08 (4.07-4.09) kg with a corresponding effort of 13.22 (13.15-13.29) units of f_{msy} and for small shrimp were 4.43 (4.42-4.44) kg and 3.99 (3.98-4.00) kg with a corresponding effort of 9.40 (9.39-9.41) units of f_{msy} respectively from the stochastic models. The results suggest that the TAC should be included in current management measures to ensure a long-term sustainable utilization of these stocks.

Table of Contents

Content	Page No.
Acknowledgement	I
Abstract	II
Table of Contents	III-IV
List of tables	V
List of figures	VI
Chapter-1 Introduction	1-5
1.1 Background of the study	1-4
1.2 Objectives of the study	5
Chapter-2 Review of literature	6-11
2.1 Theoretical aspects	6-8
2.2 Scientific literature review	8-11
Chapter-3 Materials and methods	12-17
3.1 Selection of the study area	12
3.2 Study period	13
3.3 Data collection	13
3.4 Fishing operation	13-14
3.5 MSY estimation	15-17
3.6 Data assessment	17
Chapter-4 Results	18-35
4.1 Species wise CPUE for the Pasur River fishery	18
4.2 Estimated parameters for inland fish	18-20
4.2.1 MSY and f_{msy} using Schaefer and Fox Model	21-24

Content	Page No.
4.2.2 Deterministic Observation-Error Estimator	24-26
4.2.3 Stochastic Observation-Error Estimator	27
4.3 Estimated parameters for Small Shrimp	27-28
4.3.1 MSY and f_{msy} using Schaefer and Fox model	29-32
4.3.2 Deterministic Observation-Error Estimator	32-34
4.3.3 Stochastic Observation-Error Estimator	35
Chapter-5 Discussion	36-38
Chapter-6 Conclusion	39
Chapter-7 References	40-44
Chapter-8 Appendix	45-50



List of Tables

Table No.	Title	Page No.
Table-1	Characteristics of set bag net	14
Table-2	Estimation of CPUE by using four years record for major groups	19
Table-3	MSY and f_{msy} following Month wise CPUE are estimated for inland Fish	20
Table-4	Worksheet for drawing a Schaefer and Fox curve for inland Fish	22
Table-5	Results of the application of Schaefer and Fox models	24
Table-6	Estimated CPUE, C_t/MSY and f_t/f_{msy} for inland fish	24-25
Table-7	Summary of output derived from Monte Carlo simulations for inland fish	27
Table-8	MSY and f_{msy} following Month wise CPUE are estimated for small shrimp	28
Table-9	Worksheet for drawing a Schaefer and Fox curve for small shrimp	30
Table-10	Results of the application of Schaefer and Fox models	32
Table-11	Estimated CPUE, C_t/MSY and f_t/f_{msy} for small shrimp	32-33
Table-12	Summary of output derived from Monte Carlo simulations for small shrimp	35



List of Figures

Figure No.	Title	Page No.
Fig-1	MSY is determined between Population size (N) corresponding time (t)	6
Fig-2	Illustration of the different assumptions behind the Schaefer and Fox model	8
Fig-3	Location of the study area in Pasur River	12
Fig-4	Using set bag net by the fishermen	13
Fig-5	Relationship between a) CPUE and Fishing effort for Schaefer model (inland) b) Log-CPUE and Fishing effort for Fox model	21
Fig-6	Schaefer and Fox equilibrium yield curves for inland fish	23
Fig-7	The observed and estimated CPUE of the inland fish	25
Fig-8	The ratio of a) Estimated fishing effort (f_i) and f_{msy} for inland fish b) Estimated yield (C_i) and MSY for inland fish	26
Fig-9	Relationship between a) CPUE and Fishing effort for Schaefer model (Shrimp) b) Log-CPUE and Fishing effort for Fox model	29
Fig-10	Schaefer and Fox equilibrium yield curves for small shrimp	31
Fig-11	The observed and estimated CPUE for small shrimp	33
Fig-12	The ratio of a) Estimated fishing effort (f_i) and f_{msy} for small shrimp b) Estimated yield (C_i) and MSY for small shrimp	34

Chapter One

INTRODUCTION

1. Introduction

1.1 Background of the study

Bangladesh has a vast fisheries resources comprising of fresh, brackish and marine waters inhabited by 260 fresh and brackish water species, 475 marine species, 12 exotic fish species, 36 marine shrimp species and 24 species of prawn (DoF, 2015). Fish is a source of valuable animal protein and makes a major contribution to the economy of Bangladesh by earning foreign exchange. Bangladesh has earned an amount of tk. 4,898.22 crore in 2015 from its export (FAO, 2015). Fisheries sector contributed 3.69% to national GDP and provides 60% of national animal protein consumption (DoF, 2015). Inland capture and culture fisheries resources are a vital component in the livelihoods of people in many parts of the developed and developing world. Based on current statistical information, inland fisheries account for 2.13% of animal protein sources. This figure is very likely to be underestimated as compared with their 4.04% contribution to the annual growth rate, as about 90% of fish from inland capture is for human consumption. Per capita supply of fish and fishery products from capture and aquaculture reached for 19.30 kg. The capture and culture fish production of Bangladesh is 9, 95,805 MT and 19, 56,925 MT respectively (DoF, 2015). Fish production from aquaculture has increased to a great extent but open water fish production is in slow progress. Now only about 28.07% of total fish production comes from inland open water. With the increase of population, fishing effort or pressure is increasing. For that reason, maintaining sufficient stocks of target species to ensure a viable population is required.

In the southwestern part of Bangladesh, the Pasur is one of the most important rivers in Khulna District. The total length of the river is about 142 km and is blessed with diversified fish species like Major carp (Ruhi, Catla, Mrigal), Common carp, Orange-fin labeo, Boggut labeo, Yellowtail catfish, Wallago, Snakehead murrel/Spotted snakehead, Walking catfish, Stinging catfish/African catfish, other Inland and marine fishes, Giant freshwater prawn, Giant tiger shrimp etc. A large number of fishermen are harvesting these resources everyday using the gears like set bag net, gill net and cast net etc. The fish biomass and level of the fish exploitation are still unknown and ultimately hindering the management of these river fisheries. In addition, specific gear base in MSY is unknown.

In general, there are several fisheries management measures that divided into two categories like-input control measure and output control measure. Input controls can include restrictions on the number of fishing units through limiting the number of licenses or permits issued restrictions on the amount of time units for fishing, such as individual effort quotas. Output (catch) controls usually involve setting a total allowable catch (TAC) which is one important management tool in commercial fisheries. These are intended to allocate fish resources to different member states and to control the amount of fish removed each year. This tool is central for different types of management systems ranging from global quotas to individual transferable quotas. In fact, the decision about the TAC level must reconcile individual demands of different fishermen with the conservation of a fishing stock. TAC is sub-divided into individual quotas by fishing nation, fleet, fishing company, or fishermen (e.g. in the case of individual quotas), limiting by catch etc. (Pope, 1983). This management measures are frequently used for maintaining Maximum Sustainable Yield (MSY), Maximum Economic Yield (MEY), Surplus Production Model like Schaefer and Fox model etc. However, the stock status is still little known although several attempts have been made to estimate the MSY, f_{msy} or TAC for fish species.

In population ecology and economics, Maximum sustainable yield (MSY) is, theoretically, the largest number (weight) of a species that can be taken from the stock of any fishery in such a way that stock may not be affected for long period of time, which is a key tool for the better management of a fishery. The concept of MSY aims to maintain the population size at the point of maximum growth rate by harvesting the individuals that would normally be added to the population, allowing the population to continue to be productive indefinitely. Under the assumption of logistic growth (Schaefer), the population size is exactly halfway to its carrying capacity and it is growing at its fastest rate. But, based on the correlation coefficients of the linear regressions, the Fox model provides a better fit to data than the Schaefer Model.

Surplus production models also called biomass dynamic models are a traditional first analytical tool for stock assessment and are important when age structured data are not easily available (Haddon, 2011). The objective of the surplus production models is to determine the optimum effort that produces the maximum yield to sustain without long-term productivity of the stock. Because fish stock always remain in non-equilibrium state due to the ever changing biological and environment factors affecting the fish stock therefore, the equilibrium models have been

failed (Hilborn and Walters, 1992). Basically, Surplus production models (Schaefer & Fox model) have been widely used in fisheries related applications because they require only simple information such as catch and effort data series. The theory behind the surplus production models has been reviewed by many authors, such as Ricker (1975), Caddy (1980), Gulland (1983) and Pauly (1984). The Schaefer model suggests that yield is related to fishing effort by a symmetrical parabola. In practice, the approach to Schaefer model is to use a long series of annual catch and effort data, and assume equilibrium conditions. In Fox production model, an expression for MSY is obtained by inserting the values of catch and effort data series. The Schaefer and Fox model suggest that yield is related to fishing effort by a symmetrical and asymmetrical parabola.

There are three methods widely used to fit the surplus production model such as effort-averaging methods, process-error estimators and observation-error estimator. Among them, only observed errors are considered in deterministic and stochastic approaches to estimate fishing parameters. Deterministic models are usually developed by statistical techniques such as linear regression or non-linear curve fitting procedures which essentially model the average system behaviors of an equilibrium or steady state relationship. A deterministic model assumes that its outcomes are certain if the input to the model is fixed. A stochastic model is a tool for estimating probability distributions of potential outcomes by allowing random variation in one or more inputs over time. The random variation is usually based on fluctuations observed in historical data for a selected period using standard time-series techniques. Distributions of potential outcomes are derived from a large number of simulations (stochastic projections) which reflect the random variation in the input(s). The Monte Carlo Simulation is an example of a stochastic model used in probability distributions. It is a problem solving technique used to approximate the probability of certain outcomes by running multiple trial runs, called simulations, using random variables.

Existing fishery management measures are based on fishermen experience rather than scientific evidences. Some aspects of renowned researchers contributed to the various production models have been well documented (Schaefer, 1954; Fox, 1970; Pella and Tomlinson, 1969; Ricker, 1975; Pitcher and Hart, 1982; Hilborn and Walters, 1992; Laloe, 1994; Prager, 1994, 2005; Walter and Perma, 1996; Quinn and Deriso, 1999; Maunder *et al.*, 2006; Balli *et al.*, 2011; Kumar, 2012). But there was no scientific literature on maximum sustainable yield (MSY) for

the Pasur River fishery in Bangladesh using surplus production models. However, the stock status is still unknown although several attempts have been made to estimate the maximum sustainable yield (MSY) or total allowable catch (TAC) of major species. Ricker (1975) opined that the production of a fish or other aquatic animals is often sought as a means of establishing an upper limit to the annual harvest. Since the fish stocks remain unstable or at non-equilibrium state because of natural fish mortality or environmental fluctuations, equilibrium modeling has failed (Hilborn and Walters, 1992). Sissenwine and Shepherd (1987) demonstrated that there are two traditional approaches for estimating surplus-production models and maximum sustainable yield or reference point: a) surplus production models or biomass dynamics models b) biomass-per-recruit, spawner per-recruit and yield-per-recruit estimators. However, MSY parameters estimations from the surplus production model can be directly estimated from the catch and effort or CPUE data (Polacheck *et al.*, 1993). Recently some published works are available which have been done on MSY of different aspects of biology of fish species from Pakistani waters and East China Sea (Panhwar *et al.*, 2012a, b; Siyal *et al.*, 2013; Wang and Liu, 2013). In only a few papers authors tried to estimate the MSY, fishing effort at MSY (f_{msy}), and TAC have been done by different researchers (Chen, 1999; Jong, 2001; Miao *et al.*, 2006; Hong, 2008; Wu, C. C. and Ou, C. H., 2010) using both deterministic and stochastic observation-error estimator approaches. Despite a huge commercial demand of river fishery, no published information is available on the stock assessment for the Pasur River or even for river fisheries in Bangladesh.

Therefore, the present study aimed at representing an analysis of the data concerning catch, effort and catch per unit of fishing effort (CPUE) for the river of Pasur at the District of Fisheries in Khulna as well as the estimation of the maximum sustainable yield (MSY), fishing effort at MSY (f_{msy}) and TAC of the major fishing resources by using Schaefer, Fox model and both deterministic and stochastic observation-error estimator approaches.

1.2 Objectives of the study

The study was initiated by setting the following objectives:

- ✓ Guesstimate the MSY and fishing effort at MSY (f_{msy}) for the Pasur River fishery by using Schaefer and Fox model.
- ✓ Determination of the fisheries management measures (TAC) with the approaches of deterministic and stochastic observation-error approaches.

The results obtained in the present study can be used as a reference of setting management measure for the Pasur River fishery.

Chapter Two

LITERATURE REVIEW



2. Literature Review

2.1 Theoretical aspects

MSY: Maximum sustainable yield (MSY) is a term used in fishery management to describe the highest average catch that does not reduce a stock's abundance over time, taking into account the stocks reproductive and growth capacities under prevailing environmental conditions. MSY is typically determined for a single species, thereby ignoring effects on or from other species. Multispecies maximum sustainable yield (M_{msy}) is the highest average catch (by weight) of all target species in a region that could be caught over time without causing a decline in any single species. The idea that fisheries have a “maximum sustainable yield” was first articulated in the mid-20th Century.

Implication of MSY: Starting to harvest a previously unharvested population will always lead to a decrease in the population size. It is impossible for a harvested population to remain at its original carrying capacity. Instead, the population will either stabilize at a new lower equilibrium size or, if the harvesting rate is too high, decline to zero.

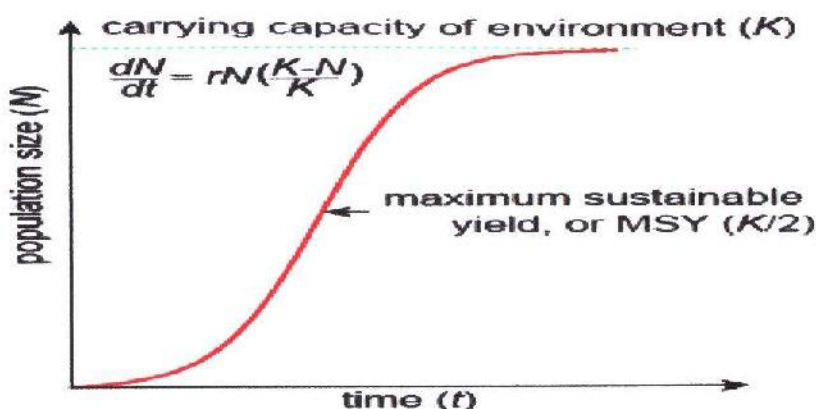


Fig-1: MSY is determined between Population size (N) corresponding time (t).

The reason for which populations can be sustainably harvested is that they exhibit a density-dependent response (Russell, 1931). This means that at any population size below K, the population is producing a surplus yield that is available for harvesting without reducing population size. Density dependence is the regulator process that allows the population to return

to equilibrium after a perturbation. The logistic equation assumes that density dependence takes the form of negative feedback.

If a constant number of individuals are harvested from a population at a level greater than the MSY, the population will decline to extinction. Harvesting below the MSY level leads to a stable equilibrium population if the starting population is above the unstable equilibrium population size.

Limitations of MSY approach

The concept of maximum sustainable yield is not always easy to apply in practice. Estimation problems arise due to poor assumptions in some models and lack of reliability of the data. Biologists, for example, do not always have enough data to make a clear determination of the population's size and growth rate. Calculating the point at which a population begins to slow from competition is also very difficult. As a management goal, the static interpretation of MSY (i.e. MSY as a fixed catch that can be taken year after year) is generally not appropriate because it ignores the fact that fish populations undergo natural fluctuations (i.e. MSY treats the environment as unvarying) in abundance and will ultimately become severely depleted under a constant catch strategy. Thus, most fisheries scientists now interpret MSY in a more dynamic sense as the maximum average yield (MAY) obtained by applying a specific harvesting strategy to a fluctuating resource.

Selection of model in MSY estimation

According to Sparre and Venema (1998) it can be reported that the estimation of maximum sustainable yield using surplus production model based on Schaefer and Fox model. Both models conform to the assumption that Y/f declines as effort increases, but they differ in the sense that the Schaefer model implies one effort level for which Y/f equals zero, namely when $f = -a/b$ whereas in the Fox model, Y/f is greater than zero for all values of f . They suggest that if the fishing effort (f) close to zero then Y/f takes the maximum value. When increasing f from zero to level A (Fig. 02) the two curves are approximately equal, but to the right of A the differences become larger. Thus, the choice between the two models becomes important only when relatively large values of f are reached. It cannot be proved that one of the two models is superior to the other. So, I choose the most reasonable in each particular case or the one which gives the

Mainardi (2010) published that the Traditional surplus production models are based on fish population dynamics and distribution, fish catch, and fishing effort, and can provide guidelines for fisheries management. This approach is applied to marine fisheries in Indonesia (Java Sea) and Papua New Guinea, and results are compared with traditional model.

Lavania-Baloo *et al.* (2012) published that Maximum Sustainable Yield (MSY) was applied to investigate the *Gracilaria edulis* in shrimp pond water for six weeks as phytoremediation agent. The active and inactive biomass were partitioned and logistic model ($R^2 = 0.980$) was modified when 239.2g of biomass was for inactive propagation. According to the result, MSY was 0.68g/day at 12.02g of active biomass and the simulated logistic model for biomass growth ($R^2 = 0.986$).

Chakraborty *et al.* (1996) reported the growth, mortality, recruitment pattern and MSY in fishery resources of Maharashtra and investigated 18 fish resources of which 11 are optimally exploited. The penaeid prawn was underexploited and Cephalopods were exploited. The yield of fishes, prawns, and cephalopods were 65083, 38404 and 11373 tons while the estimated MSY had been 83025, 72460 and 10475 tons.

Wu *et al.* (2010) estimated the sergestid shrimp (*Sergia lucens*) in the southwestern Taiwan and MSY, TAC and fishing effort at MSY (f_{msy}) were estimated to be 1008 tons, 907 tons and 11292 vessel-days, respectively by using the surplus production model based on a catch and effort series from 1997-2008 with deterministic observation-error estimator. Furthermore, the mean MSY, TAC, and f_{msy} with 95% CI were estimated to be 1011 (842-1243) tons, 910 (758-1119) tons, and 11296 (10758-11807) vessel-day, respectively from the stochastic models.

Kanik and Kucuksenel (2013) reported that Common Fisheries Policy (CFP) was supported to achieve maximum sustainable yield (MSY) for all European fisheries by 2015. If we assume that fishermen are remaining within their quotas through capturing untargeted fish after targeted fish is fully caught simply it is derived from catchability coefficients.

Brodziak and Ishimura (2010) reported that Production model of maximum sustainable yield were conducted of swordfish in 2009 and 2010 by the Western and Central (WCPO) and the Eastern Pacific (EPO). They estimated maximum sustainable yield based on Bayesian surplus production models for the two swordfish stocks by the ISC Billfish Working Group.

Kalhor et al. (2013) published that Maximum Sustainable Yield (MSY) of Bombay duck (*Harpodon neherus*) fishery from Pakistan was estimated from the catch and effort data during 1995-2009 by using CEDA and ASPIC non-equilibrium surplus production models. The estimated MSY values from Fox model and three error assumptions were 25.57 ton ($R^2 = 0.900$), 31.42 ton ($R^2 = 0.916$), 29.11 ton ($R^2 = 0.909$), respectively, while from Schaefer and Pella-Tomlinson models were 27.34 ton ($R^2 = 0.895$), 36.64 ton ($R^2 = 0.911$), 32.54 ton ($R^2 = 0.903$) from three different error assumptions respectively.

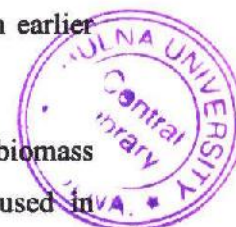
Lugten and Andrew (2008) published that the marine capture fisheries was dominated by management based on maximum sustainable yield (MSY). This study examines the law, science, politics and practice of MSY being used in the management of single fish species and as part of an ecosystem.

Mueter and Megrey (2006) observed that to estimate maximum multi-species surplus production of the ground fish is complex. Maximum multi-species surplus production was estimated approximately 2.5×10^6 ton in the Bering Sea/Aleutian Islands and 330×10^3 ton in the Gulf of Alaska. This point estimates were smaller than the sum of single-species MSY proxies from recent stock assessments, and estimates for the Gulf of Alaska were much smaller than earlier estimates.

Die and Caddy (1997) suggested that to calculate maximum sustainable yield from biomass estimates, but the classical approach of Gulland, $MSY = 0.5MB_0$, is still widely used in theoretical and practical evidence but the alternative methods are available.

Puthy (2007) estimated MSY and MEY in mackerel fishery using Schaefer and Fox model and surplus production and biomass dynamic was used to determine the utilization of mackerel stocks. The estimated MSY was 5,876 tonnes corresponding to approximately 152 boats of optimum effort. The virgin stock biomass and maximum profit & economic rents were 15,467 tonnes and US\$ 2 million respectively.

Gaertner et al. (2000) suggested that when fishing effort data are not available than catch data is to used only. Grainger and Garcia showed that the changes in time the rate of catch increase when a stock reaches its over-fishing level. They studied yellow-fin tuna (*Thunnus albacares*)



fishery in the Eastern Atlantic to show the relationship between MSY estimates from standard equilibrium production models.

Chantarasri (1994) reported that the integrated fisheries resources of some economic species like finfish, shrimp, prawn, crab etc. were exploited in Sundarbans. Two types of nets were used to catch the “present yield and MSY of tiger prawn fry”, “Present yield and MSY of oyster’s dead shell” and “Present yield and MSY of gastropods” were “334 million and 672 million”, “3080 tons and 6076 tons”, “35 tons and 113 tons” respectively.

Siyal *et al.* (2013) published MSY estimates of the silver pomfret, *Pampus argenteus* fishery based on the time series catch and effort data from 1989 to 2009 in Pakistan. Three surplus production models and three model error assumptions were estimated by CEDA computer programme and two SPMs were estimated ASPIC package. Estimated biological reference point (e.g. MSY) with ASPIC were Fox model 5525 mt and $F_{MSY} = 1619$, coefficient of variation was 1.0 and coefficient of determination $R_2 = 0.58$ and the catch-ability coefficient $q = 0.00077$ were estimated.

Garcia *et al.* (1989) published that maximum sustainable yield (MSY) estimates by using surplus production models of Schaefer and Fox can be expressed in terms of fishing mortality that yields maximum sustainable yield (f_{msy}) annual yield and mean biomass. If f_{msy} is known, it becomes possible to estimate MSY and describe the surplus production function even when the data are limited to one year of estimates for catch and mean biomass.

Chapter Three

MATERIALS AND METHODS

3. Materials and Methods

3.1 Selection of the study area

Khulna region is located in the southwest part of Bangladesh. There are many rivers found in Khulna region such as Rupsa-Pasur River, Bhairab River, Shibsha River, Dharla River, Bhadra River, Ball River and Kobadak River. Among them, the Pasur River is one of the largest and economically significant rivers in Khulna region. A large number of people directly and indirectly involved in fishing on this river for their livelihood. But day by day the fish production of this river was declining drastically. So the people depend on the fishery were facing threat on their income source. For this reason, this river was selected in the present study. The study area is shown in the following figure-03.

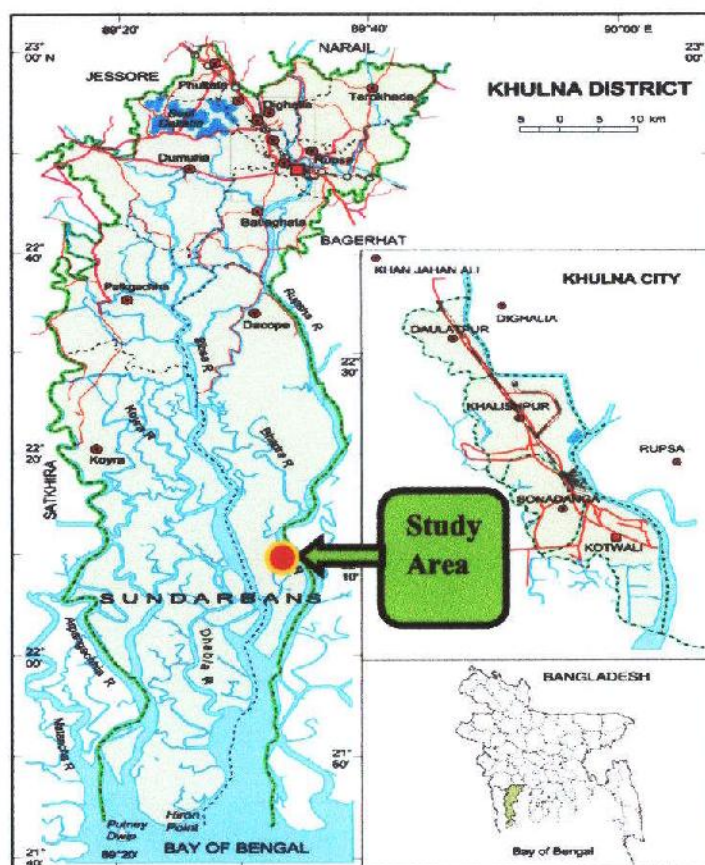


Fig-03: Location of the study area in the Pasur River

3.2 Study period

The study was based on the Secondary data recorded in the year from the Pasur River during the fishing seasons from 2011 to 2014.

3.3 Data collection

Secondary data were collected from District Fisheries office in Khulna. The data were based on the records of catch assessment survey focusing on the Pasur River adjacent to ~~the location~~ Village- Khalshi, Union- Chalna and Upazilla- Dacope. River wise catch assessment forms are attached in the Appendix-2. Other Secondary information sources had been reviewed in order to highlight particular issues and gaps in knowledge. Secondary information was collected from different publications and extension booklets made from Department of Fisheries (DoF), books and journals.

3.4 Fishing operation

In the Pasur River, the fishermen used different types of net to catch a large number of fish. These were set bag net, gill net, cast net etc. The present study, only set bag net (behundi jal) was chosen because the net was mostly utilized for fishing in the Pasur River.



Fig-04: Using set bag net by the fishermen

The set bag net (behundi jal) was a fixed tapering net, resembling a trawl net, set in the tidal stream by attaching it to hold-fasts. It had a rectangular mouth kept open by two vertical bamboo

the net (wing tips) to hold-fasts by means of long bamboo poles and steel wires. The hold-fasts were two wooden stakes embedded some distance apart in the sea bed, so that the net was parallel to the direction of the current. The length and depth of set bag net were 45.72 m and 4.57 m respectively. The mesh size was 2.5 -3.0 inches at the mouth and 1.0-1.5 inches at the cod end. However, the Specification of net dimension has been described in the following table-1.

Table-1: Characteristics of set bag net

Components	Size Range
Mesh size	2.5 -3.0 inch at the mouth 1.0-1.5 inch at the cod end
Length	45.72 m
Area of operation	334.45 m ²
Depth	4.57 m
Time of operation	6.00 A.M.-12.00 P.M. (at day) 12.00 A.M.-6.00 A.M. (at night)

Calculation of Unit effort:

The unit of effort is an essential part of planning work. Unit of effort might be hours per person, days, weeks, or something else. For example, some teams use the "ideal hour" as their standard unit of effort. According to Mickel King (*Fisheries Biology, Assessment and Management*), unit was calculated if a fisherman catches 20 fishes per hour in one area and 40 fishes per hour in a second area the inference is that there are twice as many fishes in the second area. If all these conditions are met, one unit of fishing effort will catch a constant proportion of a total homogeneous stock. But this study, unit of effort was calculated in the following way:

$$\text{Unit of effort} \approx (\text{Length} \times \text{Depth}) \text{ m}^2$$

$$\approx (45.72 \times 4.57) \text{ m}^2$$

$$\approx 200 \text{ m}^2 \text{ SBN/day (Approximately)}$$

3.5 MSY estimation

Initially species (individual) wise total yield (kg) and effort (units) data were estimated by using four years records obtained from the monthly (2 days in each month) surveyed catch assessment form. Then catch per unit effort (CPUE) was estimated by dividing the yield with corresponding effort and total CPUE was summed by using Schaefer and Fox model.

Schaefer Model

Catch per unit effort was calculated in the following equation,

$$CPUE = (Y/f) = \text{yield/effort}$$

$$\text{Or, } I_t = C_t/f_t \dots\dots\dots (i)$$

The Schaefer's model expresses the yield per unit of fishing effort as a function of effort as follows:

From the surplus yield model, equation may be form, $CPUE = a + bf$

$$Y = af + bf^2 \dots\dots\dots (ii)$$

Where Y = catch, f = effort ; a and b are constants whose values can be estimated by least square method and the corresponding yield curve can be given by the following equation:

Finally slope b and intercept a were calculated using the following equations,

$$b = \frac{n(\sum CPUE \times f) - (\sum f \times \sum CPUE)}{n(\sum f^2) - (\sum f)^2} \dots\dots\dots (iii)$$

$$a = \overline{CPUE} - b\overline{f} \dots\dots\dots (iv)$$

Then, MSY and f_{msy} were calculated from the following equation,

$$MSY = -\frac{a^2}{4b} \dots\dots\dots (v)$$

$$\text{Optimum effort, } f_{msy} = -\frac{a}{2b} \dots\dots\dots (vi)$$

In addition, the TAC was assumed to be 90% of the MSY.

Fox Model

A number of variations on MSY modeling exist. Among them was a model by Fox (1970) that uses an asymmetric effort curve, rather than the Schaefer symmetric parabola.

In Fox Model, the curve may be converted to a straight line by using natural logarithms:

$$\ln [\text{CPUE}] = \ln(Y/f) = a + bf \dots\dots\dots (vii)$$

The constants (a and b) of the Fox model ($\text{Yield} = f \exp [a + bf]$) were estimated by a linear regression with logarithmically transformed CPUE as the dependent variable (y) and total standardized effort as the independent variable (x).

In which, MSY and f_{msy} in Fox model were calculated from the following equation,

$$\text{MSY} = (-1/b) \exp [a-1] \dots\dots\dots (viii)$$

$$f_{msy} = -1/b \dots\dots\dots (ix)$$

Where, Y = catch, E = effort and a , b = estimate parameters

Deterministic Observation-Error Estimator

In deterministic approach, only observed-errors were considered in the model which assumed that all of the errors occurred in the relationship between stock biomass and the CPUE. The stock biomass was estimated by projecting the initial biomass forward under the historic annual catches. Then, the CPUE could be estimated by the equation below.

$$\hat{I}_t = \hat{C}_t / f_t \dots\dots\dots (x)$$

Where, $\hat{I}_t$ was the estimated CPUE at year t , $\hat{C}_t$ was the estimated catch at year t , f_t was the fishing effort during year t .

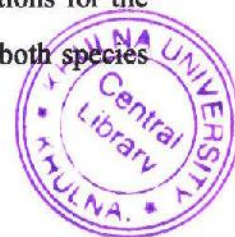
Stochastic Observation-Error Estimator

In stochastic approach, a fixed observation-error was also applied in the simulations. To avoid the uncertainty on estimation fishing parameters, the most common way of an estimator, Monte-Carlo simulation, was applied in the present study. The Monte Carlo simulations consisted of randomly drawing values of the biomass.

The standard deviation (σ) was set to be 0.01 which was equal to incorporate 1% random error of CV (coefficient of variation) into the model. The expected values of parameters approximated to the corresponding means obtained from the Monte Carlo simulations. The distributions for the model outputs such as the yield, MSY and f_{msy} were based on 100 replications for both species and the 100% were used as approximate 95% confidence intervals.

3.6 Data assessment

Data from Catch assessment records were coded and entered into a database system using Microsoft Excel-2007 and R software. Analysis and Graphical presentation were also done by the softwares. The results were prepared in a ranking order with logical explanations.



Chapter Four

RESULTS

4. Results

The results were mentioned in this chapter following the estimation of the Maximum sustainable yield in the Pasur River fishery.

4.1 Species wise CPUE for the Pasur River fishery

Estimated CPUE in the Pasur River fishery was 1.35 kg/unit for four years records from 2011 to 2014. The results are shown in Table-2. The potential yield estimates were 222.79 kg for the inland fish, 207.64 kg for small shrimp and 363.79 kg for others species on the basis of the sampling data. The year wise fishing effort was always same for different species but yields were varying for their number of sample units. CPUE ranges from 0.00 (lower) to 0.38 kg/unit (higher). Considering CPUE, the “other inland fish” comprised with Chapila (Indian River Shad), Bacha (*Eutropiichthys vacha*), Snakehead (Shol, Gazar, Taki), Catfish (Boal, Pangas, Silon, Aor, Bacha), Tilapia (*Mozambique Tilapia*), Silver carp (*Hypophthalmichthys molitrix*), Thai Pangas (*Pangasius hypophthalmus*), Sarpunti (*Puntius sarana*), Poa (*Pama croaker*) and “other small shrimp” comprised with tiger shrimp (*Penaeus monodon*), the brown shrimp (*Metapenaeus monoceros*), and the white shrimp (*Penaeus indicus*) etc. were highly dominated groups of species in the Pasur River. Other species like catfish, Pomfret, Bombay duck showed lower CPUE and was not considered in the present study. Therefore, the present study considered only the “other inland fish” (here after “Inland fish”) and “other small shrimp” (here after “Small shrimp”) for further analysis and explanations.

4.2 Estimated parameters for inland fish

Month wise CPUE, MSY and f_{msy} for inland fish were estimated and are shown in Table-3. The CPUE was ranged from 0.54 kg/unit in January to 0.28 kg/unit in September. The estimated fishing parameters for inland fish using various models are described below.

Table-2: Estimation of CPUE by using four years record for different major groups of species

Major species (group wise)	Yield & Effort of sampling units by 4 years										Total effort (unit)	Total yield (kg)	CPUE (kg/unit)
	2011		2012		2013		2014						
	yield	effort	yield	effort	yield	effort	yield	effort					
Major Carp (Ruhi, Catla, Mrigal)	0.00	73	0.00	163	0.00	166	0.00	186			588	0.00	0.00
Other Carp (Kalbasu, Ghania)	0.00	73	11.31	163	0.00	166	0.00	186			588	11.31	0.02
Catfish (Aire, Boal, Panges Rita, Silon)	12.75	73	39.88	163	15.20	166	0.00	186			588	67.83	0.12
Snake Head (Shol, Gazar, Taki)	2.30	73	19.01	163	0.00	166	0.00	186			588	21.31	0.04
Live fish (Koi, Singi, Margur)	0.00	73	17.62	163	0.00	166	0.00	186			588	17.62	0.03
Other Inland Fish (Chapila, Bacha, Poa)	62.80	73	40.34	163	41.75	166	77.90	186			588	222.79	0.38
Hilsa	0.00	73	0.28	163	0.00	166	0.00	186			588	0.28	0.00
Bombay Duck (lotia)	6.20	73	27.40	163	8.20	166	0.00	186			588	41.80	0.07
Indian Salmon (Lakhya)	0.00	73	2.32	163	0.00	166	0.00	186			588	2.32	0.00
Pomfret(Rup Chanda, Foli Chanda)	11.75	73	22.95	163	8.30	166	0.00	186			588	43.00	0.07
Sharks and rays (Hungor)	0.00	73	0.50	163	0.90	166	0.00	186			588	1.40	0.00
Others marine fish (Chhuri, Topposi etc)	5.50	73	16.42	163	8.10	166	0.00	186			588	30.02	0.05
Galda Shrimp	0.65	73	0.00	163	0.00	166	9.50	186			588	10.15	0.02
Bagda Shrimp	4.20	73	2.06	163	1.40	166	19.20	186			588	26.86	0.05
Other Big Shrimp	13.05	73	9.23	163	12.00	166	37.80	186			588	72.08	0.12
Other Small Shrimp (less than 10 cm)	40.35	73	63.04	163	30.95	166	73.30	186			588	207.64	0.35
Crab	8.70	73	9.11	163	0.00	166	0.00	186			588	17.81	0.03
Total											9996	794.22	1.35

**yield & effort = Monthly (from January to December) surveyed in 2 days per year

Table-3: MSY and f_{msy} following the month wise estimated CPUE for inland Fish

4.2 Inland Fish

M O N T H	YEAR										Schaefer model			Fox Model		
	Pasur 2011		Pasur 2012		Pasur 2013		Pasur 2014		CPUE	ln [CPUE]	b	a	M S Y	f_{msy}	M S Y	f_{msy}
	Total yield	Total effort	Total yield	Total effort	Total yield	Total effort	Total yield	Total effort								
Jan	7.80	6	7.86	15	1.90	14	8.90	14	0.54	-0.62						
Feb	5.75	4	4.64	14	2.00	14	8.20	14	0.45	-0.80						
Mar	6.75	4	5.21	11	2.10	14	6.80	14	0.49	-0.72						
Apr	4.70	4	3.64	13	2.30	14	4.90	15	0.34	-1.09						
May	5.00	4	2.08	13	1.50	14	7.40	16	0.34	-1.08						
Jun	6.00	5	3.31	12	2.30	14	7.30	16	0.40	-0.91	-0.030	0.75	4.66	12.49	4.61	13.51
July	7.90	8	2.20	13	2.35	14	7.00	16	0.38	-0.96						
Aug	3.10	6	1.80	14	2.35	14	7.60	16	0.30	-1.21						
Sep	1.90	4	2.30	16	2.40	14	7.20	16	0.28	-1.29						
Oct	5.25	7	2.70	14	6.00	13	3.60	16	0.35	-1.05						
Nov	4.50	8	2.60	14	7.95	13	3.10	16	0.36	-1.03						
Dec	4.15	13	2.00	14	8.60	14	5.90	17	0.36	-1.03						
Total	62.80	73	40.34	163	41.75	166	77.90	186	4.57	-11.80						

**yield & effort = Monthly (from January to December) surveyed in 2 days per year

4.2.1 MSY and f_{msy} using Schaefer and Fox Model

Relationship between Catch per unit efforts (CPUE) and Fishing effort (f) applicable for Schaefer model are shown in Fig-5(a) following linear regression model. From the model, the intercept “a” and slope “b” were found as 0.746 and -0.030 respectively. The regression model is also shown in Fig-5(a).

Similarly, Relationship between Log-transformed CPUE $\{\ln [CPUE]\}$ and Fishing effort (f) applicable for Fox model are shown in Fig-5(b) following linear regression model. From the model, the intercept “a” and slope “b” were found as -0.076 and -0.074 respectively. The regression model is also shown in Fig-5(b).

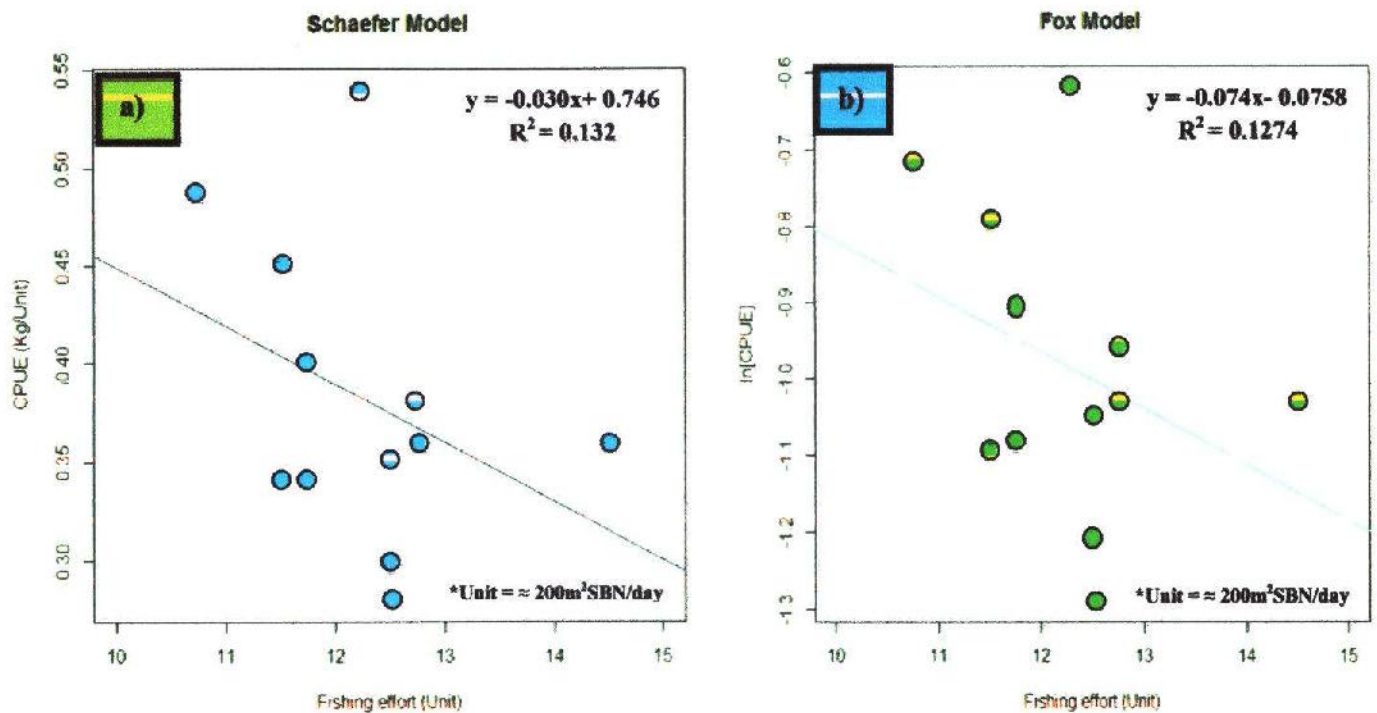


Fig-5: Relationship between a) CPUE and Fishing effort for Schaefer model and b) Log-transformed CPUE and Fishing effort for Fox model

The MSY and optimum effort (f_{msy}) for inland fish following Schaefer and Fox model equations were shown below.

In Schaefer Model,

$$MSY = -a^2/4b = -(0.746)^2 / (4 * -0.030) = 4.66 \text{ kg}$$

$$f_{msy} = -a/2b = -0.746 / (2 * -0.030) = 12.49 \text{ units}$$

In Fox Model,

$$MSY = -(1/b) \exp[a-1] = -(1/-0.074) \exp[-0.076-1] = 4.61 \text{ kg}$$

$$f_{msy} = -(1/b) = -(1/-0.074) = 13.51 \text{ units}$$

Arbitrary effort and the respective yield on basis of the obtained “a” and “b” followed by Schaefer and Fox model are mentioned in the following Table-4.

Table-4: Worksheet for drawing a Schaefer and Fox yield curve

Effort	Schaefer yield = $(af + bf^2)$	Fox yield = $f \exp(a + bf)$
0	0.00	0.00
5	3.00	3.20
10	4.50	4.42
15	4.50	4.58
20	3.00	4.22
25	0.00	3.64

The effort data and yield records obtained from the Table-4 are plotted in the following graph (Fig-6) to address the MSY and f_{msy} . In Fig-6, X-axis represents the fishing effort (unit) and Y-axis represents the Yield (kg).

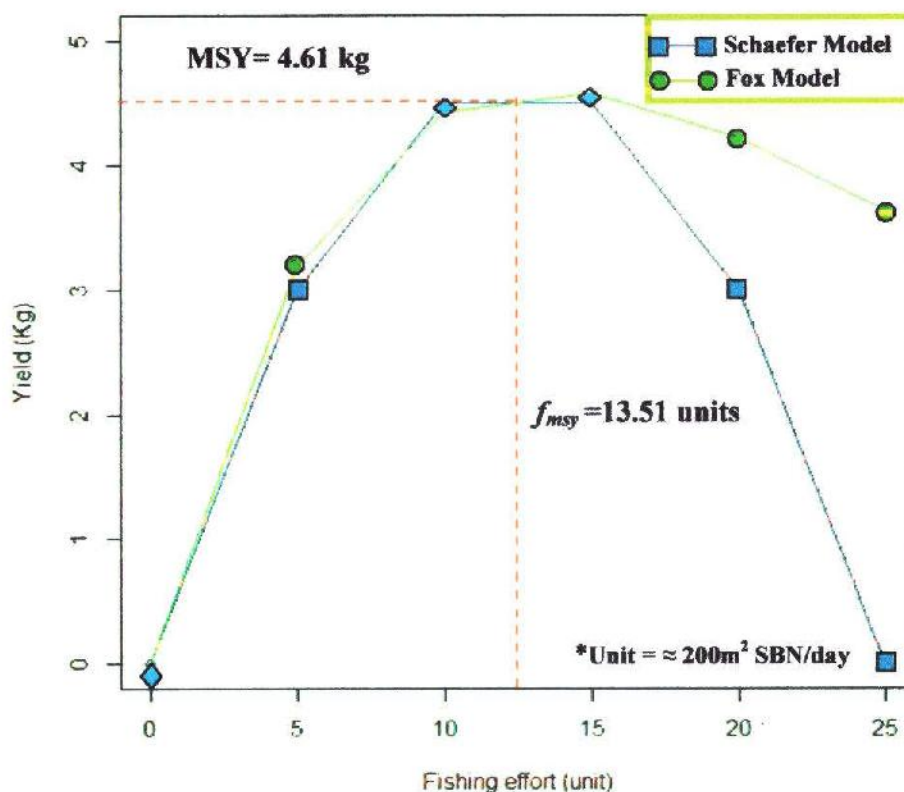


Fig-6: Schaefer and Fox equilibrium yield curves

Fig-6 shows the Schaefer and Fox equilibrium yield curves and the observed total yield and total standardized effort during the time period. The fishing efforts at maximum sustainable yield were very similar for both models. However, the Schaefer model indicates a higher level of MSY than the Fox model (Table-5).

Based on the correlation of the linear regressions, the Fox model shows higher value (slope = -0.074) than Schaefer model (slope = -0.030) and it indicates that the Fox model (Fig-6) provides a better fit to data than Schaefer Model. However, the Beaverton and Holt model (*A recognized growth estimation model*) were more suitable in Fox model, because they have a similar curvilinear relationship between CPUE and effort. For instance, if observations of Y/f plotted on f give a curve complying with the Fox model, this model might be applied without any concern for a possible biological explanation. From these above results the fox model was applied by

estimating MSY and f_{msy} for inland fish. Therefore, a sustainable yield of approximately 4.61 kg of MSY may be taken by 13.51 units of f_{msy} .

Table-5: Results of the application of Schaefer and Fox models

Model	Effort of f_{msy} (unit)	MSY (kg)
Schaefer	12.49	4.66
Fox	13.51	4.61

The MSY for Schaefer and fox model were 4.66 and 4.61 kg respectively (Table-5). The average yields of several months such as January (6.62 kg), February (5.15 kg), March (5.22 kg), June (4.73 kg), July (4.86 kg) and December (5.16 kg) were higher than the obtained MSY. Therefore, in this process, the fishing effort should be reduced for these months and restriction of the total allowable catch (TAC) needed to be applied. The CPUE was also higher in several months like January, February and March which were 0.54, 0.45 and 0.49 kg/units respectively. So in these few months, species should be closed and catching fish should be reduced in this river. If this process is fully utilized, the average yield will be balanced with MSY.

4.2.2 Deterministic Observation-Error Estimator

In the present study, only observed errors were considered in the model which assumed that all of the errors occurred in the relationship between stock biomass and the CPUE. An observation-error estimator was constructed by assuming that the biomass was deterministic and all the errors occurred in the relationship between biomass and CPUE. Estimated CPUE, C_t/MSY and f_t/f_{msy} for inland fish were calculated from the observed CPUE, MSY and f_{msy} . The estimation is shown in the following table-6.

Table-6: Estimated CPUE, C_t/MSY and f_t/f_{msy} for inland fish

Month	Yield (kg)	Effort (unit)	CPUE	Estimate CPUE	$C_t/MSY = (C_t/4.61)$	$f_t/f_{msy} = (f_t/13.51)$
January	6.62	12.25	0.54	0.38	1.43	0.91
February	5.15	11.50	0.45	0.40	1.12	0.85
March	5.22	10.75	0.49	0.42	1.13	0.80
April	3.89	11.50	0.34	0.40	0.84	0.85

Month	Yield (kg)	Effort (unit)	CPUE	Estimate CPUE	$C_t/MSY = (C_t/4.61)$	$f_t/f_{msy} = (f_t/13.51)$
May	4.00	11.75	0.34	0.39	0.87	0.87
June	4.73	11.75	0.40	0.39	1.03	0.87
July	4.86	12.75	0.38	0.37	1.05	0.94
August	3.71	12.50	0.30	0.37	0.81	0.94
September	3.45	12.50	0.28	0.37	0.75	0.93
October	4.39	12.50	0.35	0.37	0.95	0.93
November	4.54	12.75	0.36	0.37	0.98	0.94
December	5.16	14.50	0.36	0.31	1.12	1.07
Total	55.70	147.00	4.57	4.56		

* C_t = Ratio of estimated yield; * f_t = Ratio of estimated fishing effort

The observed CPUE fluctuated in the period of January to December, ranged from the peak of 0.54 in January to the lowest of 0.28 in September. The estimated CPUE decreased slightly from the highest of 0.42 in March to the lowest of 0.31 in December (Fig-7). The observed CPUE was higher in January, February, March, June, July and December than the estimated CPUE. In these few months the catch should be reduced and fisheries management measures should be taken.

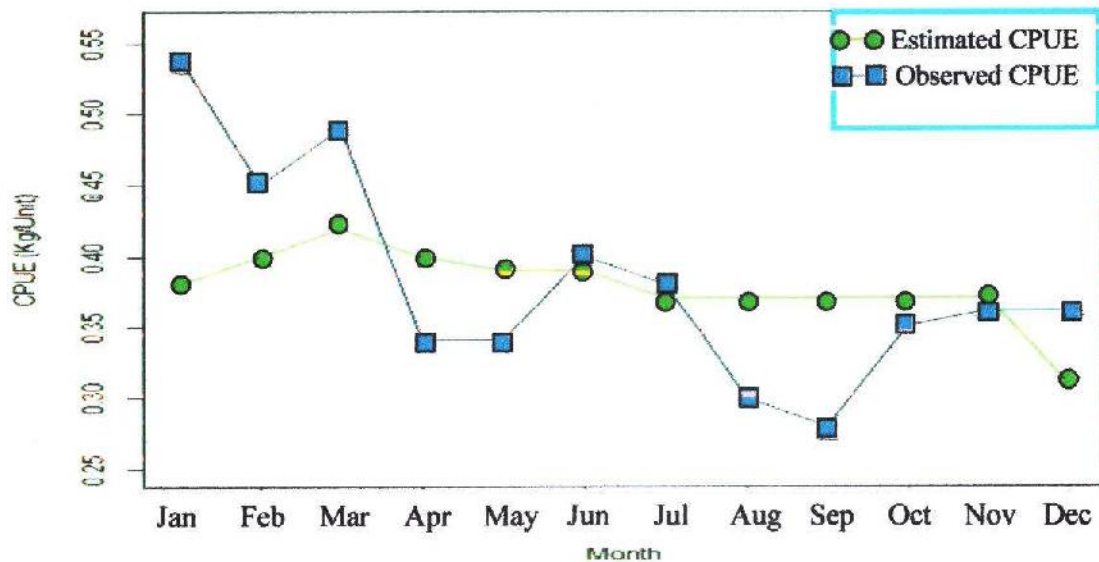


Fig-7: The observed and estimated CPUE for inland fish

The discrepancy between these two series was probably due to the measurement and sampling error (observation-error) (Fig-7).

The ratio of estimated fishing effort and f_{msy} was below 1 during the total period of January to December with the exception in December suggesting that fishing effort was under sustainable level in Fig-8(a). The ratio of f_i and f_{msy} during December suggested that the effort was exceeded.

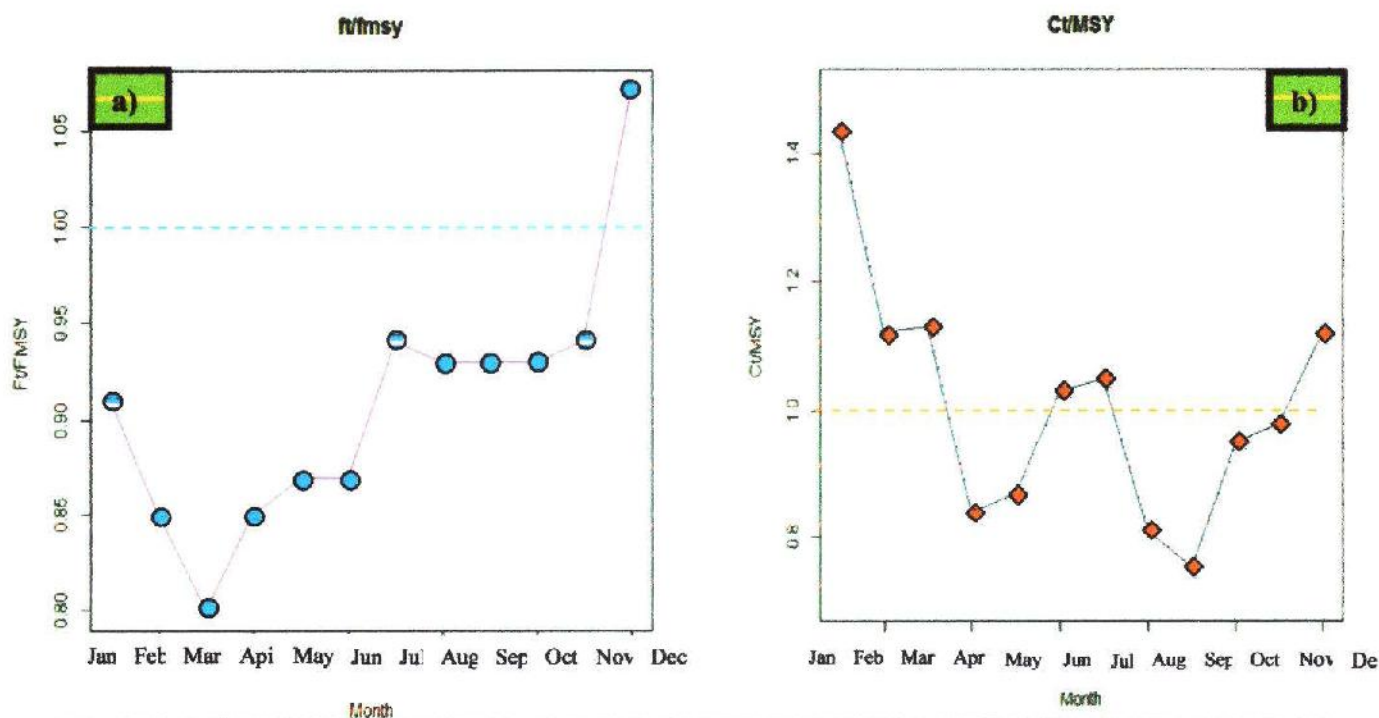


Fig-8: The ratio of a) estimated fishing effort (f_i) and the effort of MSY (f_{msy}) and b) estimated yield (C_i) and MSY for inland fish

Similarly the ratio of estimated yield (C_i) and MSY were less than 1 in six (April, May, August, September, October and November) out of twelve months in Fig-8(b) which suggested that the stock was not overfishing. But the ratio of C_i/MSY in several months like January, February, March, June, July and December were greater than 1 and it was suggesting that TAC should be maintained for this species. So, in this present study the yield was maximum in several months above the obtained MSY, the TAC should be included in current management measure to ensure a long-term sustainable utilization of this stock by close monitoring on this species. The above findings suggested that the inland fishery for the Pasur River was at a reasonable exploitation level.

4.2.3 Stochastic Observation-Error Estimator

Biomass was one of the factors that may affect the results of surplus production model. Therefore, it was a necessity to take into account the influence of this uncertainty on estimation of MSY or TAC due to the difficulty in estimating biomass which may result in high uncertainty. In the present study, a fixed observation error which was applied in a stochastic approach in the simulations. The percentile confidence intervals and distributions of the three parameters estimated based on the stochastic model were showed in Table-7.

The expected values of parameters approximated to the corresponding means obtained from the Monte Carlo simulations. The distributions for the model outputs such as the biomass, MSY and f_{msy} were based on 100 replications and the 2.5th and 97.5th percentiles were used as approximate 95% confidence intervals.

The mean MSY, TAC, and f_{msy} with 95% CI were estimated to be 4.53 (4.52-4.54) kg, 4.08 (4.07-4.09) kg, and 13.22 (13.15-13.29) units respectively from the stochastic models (Table-7) and Appendix-4.

Table-7: Summary of output derived from Monte Carlo simulations for inland fish

Stochastic	MSY (kg)	f_{msy} (unit)	TAC (kg)
Mean	4.53	13.22	4.08
95% CI_UP	4.54	13.29	4.09
95% CI_LOW	4.52	13.15	4.07

This Stochastic approach implied that the results obtained in MSY, f_{msy} and TAC for inland fish in current management measure with 95% CI but 5% error were assumed in the present study. The mean of MSY was higher than TAC and it indicates that if this measure is fully utilized, it will ensure a long-term sustainable of this stock in spite of no overfishing and overfished occurrence.

4.3 Estimated parameters for Small Shrimp

In Small shrimp, the month wise CPUE, MSY and f_{msy} were estimated and are shown in Table-8. The CPUE was ranged from 0.47 kg/unit in March to 0.23 kg/unit in August. The estimated fishing parameters for small shrimp using various models are described below.

Table-8: MSY and f_{msy} following the month wise estimated CPUE for Small Shrimp**4.3 Small Shrimp**

M O N T H	YEAR								b	a	Schaefer model			Fox Model				
	Pasur 2011		Pasur 2012		Pasur 2013		Pasur 2014				AVE_ Yield	AVE_ Effort	CPUE	ln [CPUE]	M S Y	f_{msy}	M S Y	f_{msy}
	Total yield	Total effort	Total yield	Total effort	Total yield	Total effort	Total yield	Total effort										
Jan	2.50	6	7.59	15	1.60	14	5.00	14	4.17	12.25	0.34	-1.08	-0.039	0.84	4.50	10.71	4.46	9.48
Feb	2.25	4	9.27	14	1.90	14	5.90	14	4.83	11.50	0.42	-0.87						
Mar	2.25	4	10.55	11	2.00	14	5.50	14	5.08	10.75	0.47	-0.75						
Apr	2.00	4	5.62	13	1.80	14	4.90	15	3.58	11.50	0.31	-1.17						
May	2.50	4	8.67	13	2.90	14	3.50	16	4.39	11.75	0.37	-0.98						
Jun	4.00	5	7.16	12	1.80	14	6.90	16	4.97	11.75	0.42	-0.86						
July	0.00	8	8.28	13	2.50	14	4.50	16	3.82	12.75	0.30	-1.21						
Aug	0.00	6	0.00	14	2.90	14	8.50	16	2.85	12.50	0.23	-1.48						
Sep	5.25	4	0.00	16	3.25	14	8.30	16	4.20	12.50	0.34	-1.09						
Oct	9.55	7	1.80	14	2.90	13	6.00	16	5.06	12.50	0.41	-0.90						
Nov	6.05	8	2.40	14	2.50	13	6.50	16	4.36	12.75	0.34	-1.07						
Dec	4.00	13	1.70	14	4.90	14	7.80	17	4.60	14.50	0.32	-1.155						
Total	40.35	73	63.04	163	30.95	166	73.30	186	51.91	147.00	4.27	-12.61						

**yield & effort = Monthly (from January to December) surveyed in 2 days per year

4.3.1 MSY and f_{msy} using Schaefer and Fox Model

Relationship between Catch per unit efforts (CPUE) and Fishing effort (f) applicable for Schaefer model are shown in Fig-9(a) following linear regression model. From the model, the intercept “a” and slope “b” were found as 0.837 and -0.039 respectively. The regression model is also shown in Fig-9(a).

Similarly, Relationship between Log-transformed CPUE $\{\ln [CPUE]\}$ and Fishing effort (f) applicable for Fox model are shown in Fig-9(b) following linear regression model. From the model, the intercept “a” and slope “b” were found as 0.242 and -0.105 respectively. The regression model is also shown in Fig-9(b).

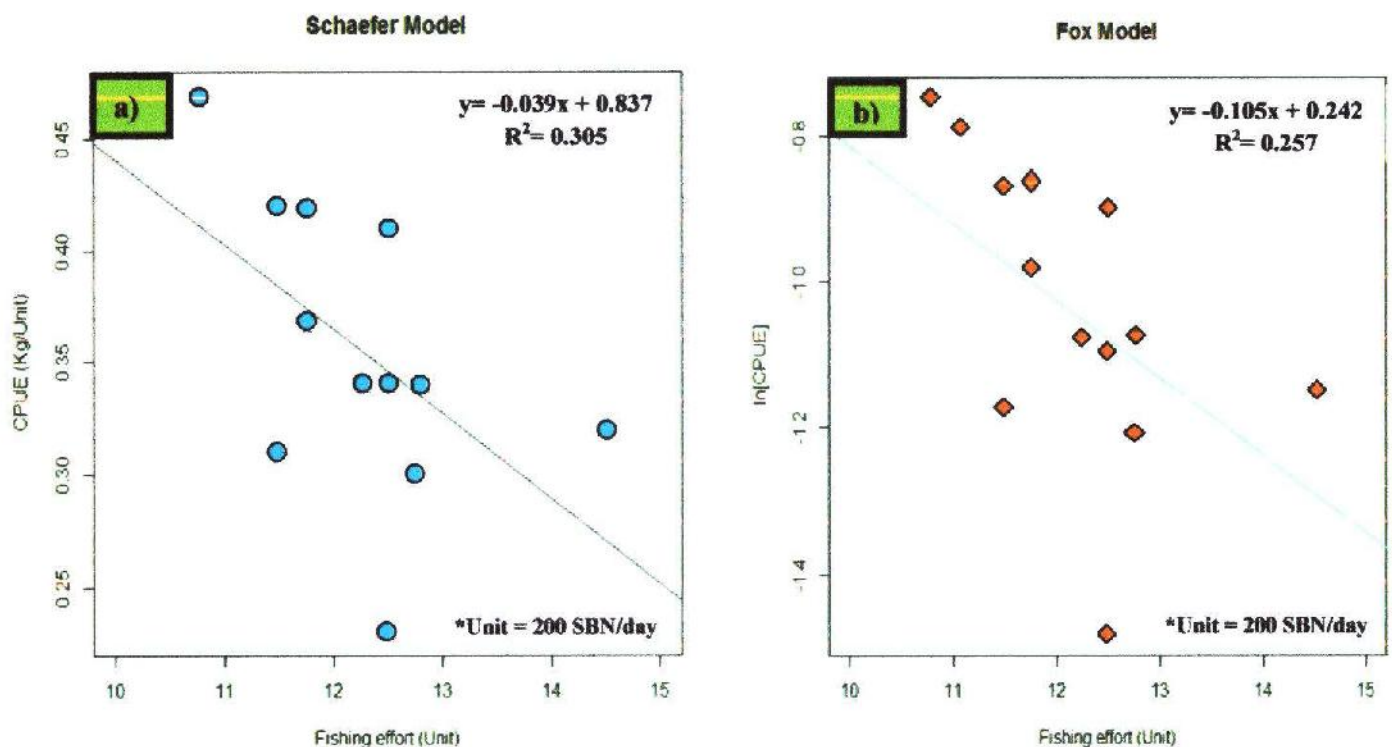


Fig-9: Relationship between a) CPUE and Fishing effort for Schaefer model and b) Log-transformed CPUE and Fishing effort for Fox model

The MSY and optimum effort (f_{msy}) for small shrimp following Schaefer and Fox model equations were shown below.

In Schaefer Model,

$$MSY = -a^2/4b = -(0.837)^2 / (4 * -0.039) = 4.50 \text{ kg}$$

$$f_{msy} = -a/2b = -0.837 / (2 * -0.039) = 10.71 \text{ units}$$

In Fox Model,

$$MSY = -(1/b) \exp [a-1] = -(1/-0.105) \exp [-0.242-1] = 4.46 \text{ kg}$$

$$f_{msy} = -(1/b) = -(1/-0.105) = 9.48 \text{ units}$$

Arbitrary effort and the respective yield on basis of the obtained “a” and “b” followed by Schaefer and Fox model are mentioned in the following Table-9.

Table-9: Worksheet for drawing a Schaefer and Fox yield curve

Effort	Schaefer yield = $(af + bf^2)$	Fox yield = $f \exp (a + bf)$
0	0.00	0.00
3	2.17	2.79
6	3.64	4.07
9	4.40	4.46
12	4.46	4.34
15	3.83	3.96
18	2.48	3.46
20	1.20	3.12

The effort data and yield records obtained from the Table-9 are plotted in the following graph (Fig-10) to address the MSY and f_{msy} . In Fig-10, X-axis represents the fishing effort (unit) and Y-axis represents the Yield (kg).

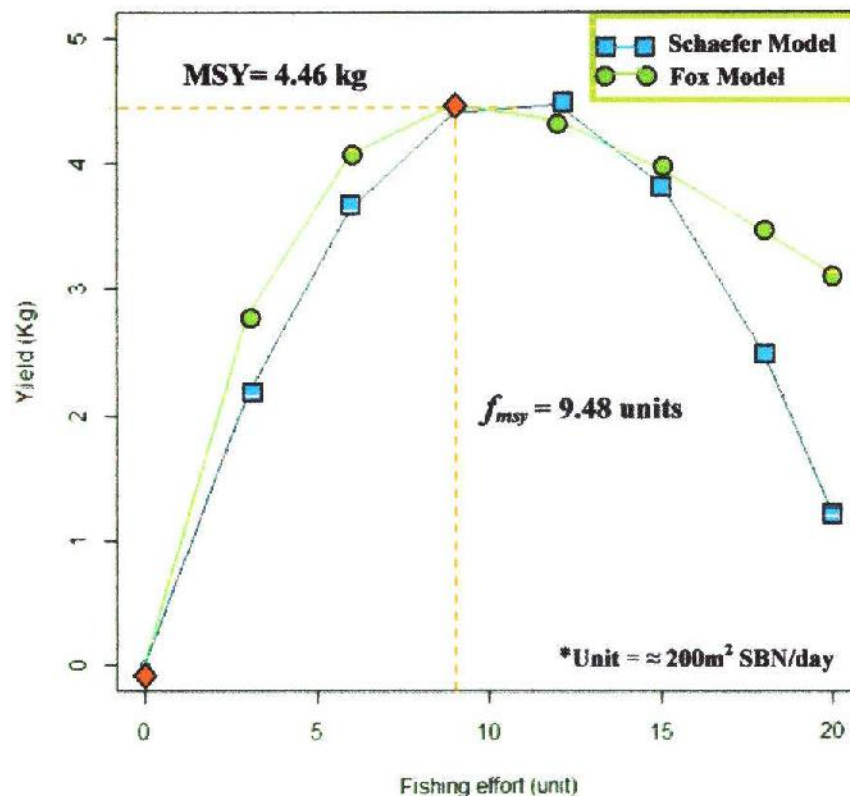


Fig-10: Schaefer and Fox equilibrium yield curves

Fig-10 shows the Schaefer and Fox equilibrium yield curves and the observed total yield and total standardized effort during the time period. The fishing efforts at maximum sustainable yield were very similar for both models. However, the Schaefer model indicates a higher level of MSY than the Fox model (Table-10).

Based on the correlation of the linear regressions, the Fox model shows higher value (slope = -0.105) than Schaefer model (slope = -0.039) and it indicates that the Fox model (Fig-9) provides a better fit to data than Schaefer Model. However, the Beverton and Holt model (a recognized growth estimation model) were more suitable in Fox model, because they have a similar curvilinear relationship between CPUE and effort. For instance, if observations of Y/f plotted on f give a curve complying with the Fox model, this model might be applied without any concern for a possible biological explanation. From these above results the fox model was applied by

estimating MSY and f_{msy} for inland fish. Therefore, a sustainable yield of approximately 4.46 kg of MSY may be taken by 9.48 units of f_{msy} .

Table-10: Results of the application of Schaefer and Fox models

Model	Effort of f_{msy} (unit)	MSY (kg)
Schaefer	10.71	4.50
Fox	9.48	4.46

The MSY for Schaefer and fox model were 4.50 and 4.46 kg respectively (Table-10). The average yields of several months such as February (4.83 kg), March (5.08 kg), June (4.97 kg), October (5.06 kg) and December (4.60 kg) were higher than the obtained MSY. Therefore, in this process, the fishing effort should be reduced for these months and restriction of the total allowable catch (TAC) needed to be applied. The CPUE was also higher in several months like February, March and June which were 0.42, 0.47 and 0.42 kg/units respectively. So in these few months, species should be closed and catching fish should be reduced in this river. If this process is fully utilized, the average yield will be balanced with MSY.

4.3.2 Deterministic Observation-Error Estimator

In the present study, only observed errors were considered in the model which assumed that all of the errors occurred in the relationship between stock biomass and the CPUE. An observation-error estimator was constructed by assuming that the biomass was deterministic and all the errors occurred in the relationship between biomass and CPUE. Estimated CPUE, C_t/MSY and f_t/f_{msy} for inland fish were calculated from the observed CPUE, MSY and f_{msy} . The estimation is shown in the following table-11.

Table-11: Estimated CPUE, C_t/MSY and f_t/f_{msy} for small shrimp

Month	Yield (kg)	Effort (unit)	CPUE	Estimate CPUE	$C_t/MSY = (C_t/4.46)$	$f_t/f_{msy} = (f_t/9.48)$
January	4.17	12.25	0.34	0.36	0.94	1.29
February	4.83	11.50	0.42	0.39	1.08	1.21
March	5.08	10.75	0.47	0.42	1.14	1.13
April	3.58	11.50	0.31	0.39	0.80	1.21
May	4.39	11.75	0.37	0.38	0.98	1.24
June	4.97	11.75	0.42	0.38	1.11	1.24

Month	Yield (kg)	Effort (unit)	CPUE	Estimate CPUE	$C_t/MSY = (C_t/4.46)$	$f_t/f_{msy} = (f_t/9.48)$
July	3.82	12.75	0.30	0.34	0.86	1.34
August	2.85	12.50	0.23	0.35	0.64	1.32
September	4.20	12.50	0.34	0.35	0.94	1.32
October	5.06	12.50	0.41	0.35	1.14	1.32
November	4.36	12.75	0.34	0.34	0.98	1.34
December	4.60	14.50	0.32	0.27	1.03	1.53
Total	45.52	147.00	4.27	4.32		

* C_t = Ratio of estimated yield; * f_t = Ratio of estimated fishing effort

The observed CPUE fluctuated in the period of January to December, ranged from the peak of 0.47 in March to the lowest of 0.23 in August. The estimated CPUE decreased slightly from the highest of 0.42 in March to the lowest of 0.27 in December (Fig-11). The observed CPUE was higher in February, March, June, October and December than the estimated CPUE. In these few months the catch should be reduced and fisheries management measures should be taken.

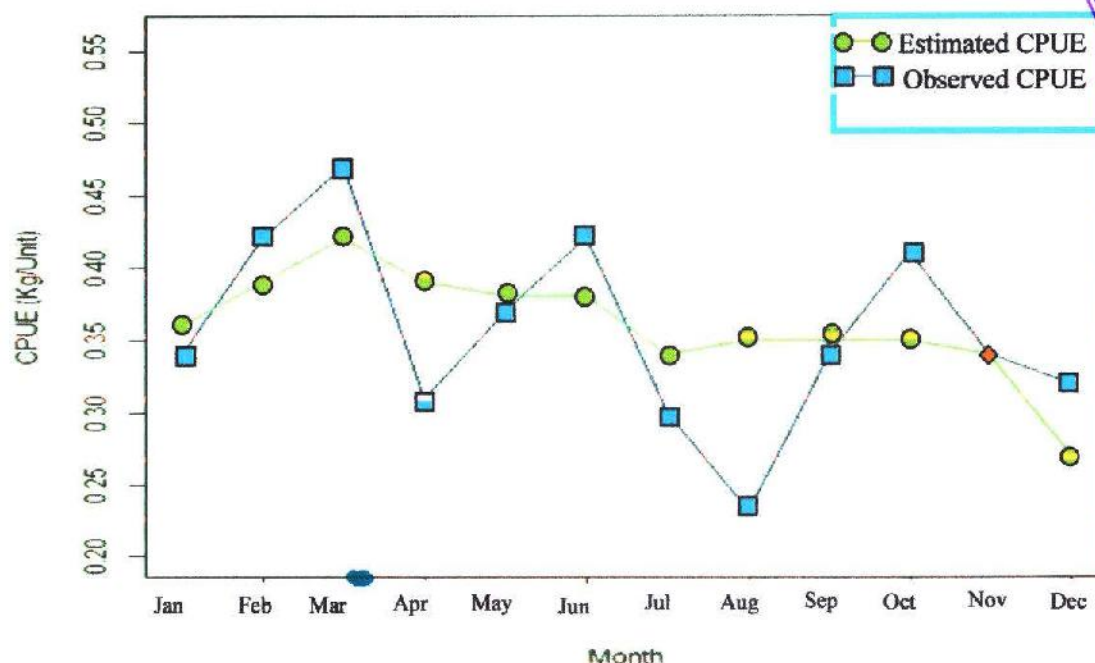


Fig-11: The observed and estimated CPUE for small shrimp

The discrepancy between these two series was probably due to the measurement and sampling error (observation-error) (Fig-11).

The ratio of estimated fishing effort and f_{msy} was above 1 during the total period of January to December suggesting that fishing effort was not under sustainable level in Fig-12(a). The ratio of f_t and f_{msy} during January to December suggested that the effort were exceeded.

This increasing trend implied that this species exceed the optimum level of effort ($f_t/f_{msy} > 1$) and close monitoring on this species is needed to ensure long-term sustainable utilization of the stock.

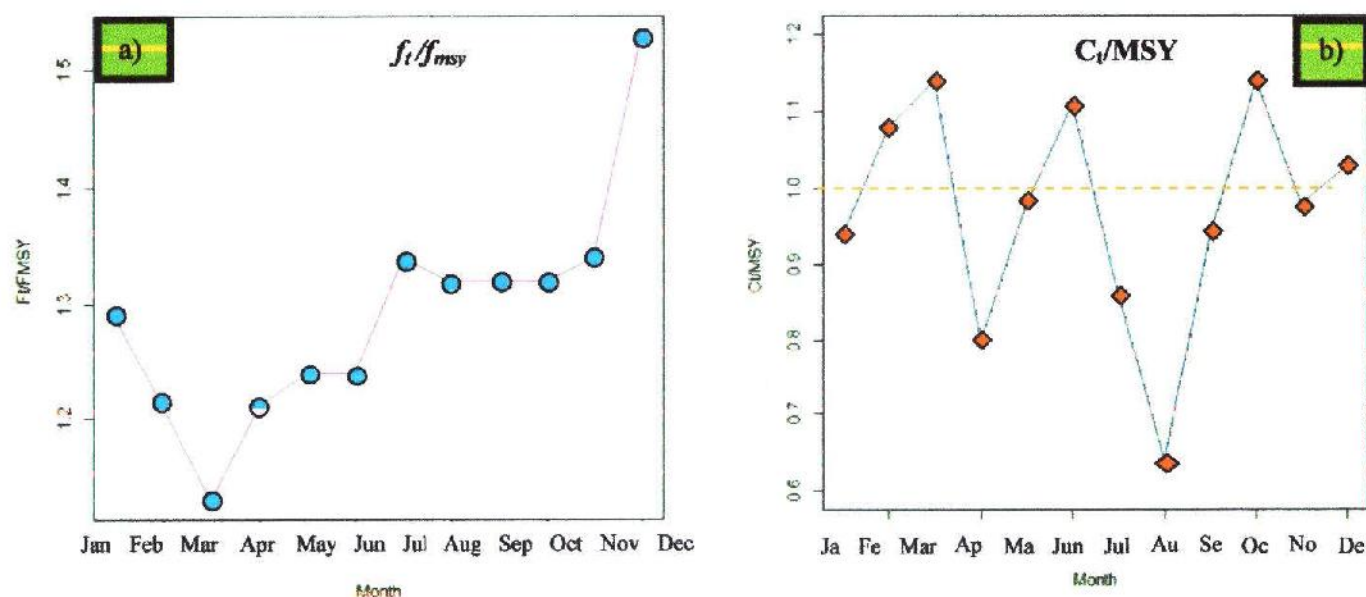


Fig-12: The ratio of **a)** estimated fishing effort (f_t) and effort of MSY (f_{msy}) **and b)** estimated yield (C_t) and MSY for small shrimp

Similarly the ratio of estimated yield (C_t) and MSY were less than 1 in seven (January, April, May, July, August, September and November) out of twelve months in Fig-12(b) which suggested that the stock was not overfishing. But the ratio of C_t/MSY in several months like February, March, June, September, October and December were greater than 1 and it was suggesting that TAC should be maintained for this species. So, in this present study the yield was maximum in several months above the obtained MSY, the TAC should be included in current management measure to ensure a long-term sustainable utilization of this stock by close

monitoring on this species. The above findings suggested that the small shrimp for the Pasur River was at a reasonable exploitation level.

4.3.3 Stochastic Observation-Error Estimator

Biomass was one of the factors that may affect the results of surplus production model. Therefore, it was a necessity to take into account the influence of this uncertainty on estimation of MSY or TAC due to the difficulty in estimating biomass which may result in high uncertainty. In the present study, a fixed observation error which was applied a stochastic approach in the simulations. The percentile confidence intervals and distributions of the three parameters estimated based on the stochastic model were showed in Table-12.

The expected values of parameters approximated to the corresponding means obtained from the Monte Carlo simulations. The distributions for the model outputs such as the biomass, MSY and f_{msy} were based on 100 replications and the 2.5th and 97.5th percentiles were used as approximate 95% confidence intervals.

The mean MSY, TAC, and f_{msy} with 95% CI were estimated to be 4.43 (4.42-4.44) kg, 3.99 (3.98-4.00) kg, and 9.40 (9.39-9.41) units respectively from the stochastic models (Table-12) and Appendix-5.

Table-12: Summary of output derived from Monte Carlo simulations for small shrimp

Stochastic	MSY (kg)	f_{msy} (unit)	TAC (kg)
Mean	4.43	9.40	3.99
95% CI_UP	4.44	9.41	4.00
95% CI_LOW	4.42	9.39	3.98

This Stochastic approach implied that the results obtained in MSY, f_{msy} and TAC for small shrimp in current management measure with 95% CI but 5% error were assumed in the present study. The mean of MSY was higher than TAC and it indicates that if this measure is fully utilized then it ensure a long-term sustainable of this stock in spite of no overfishing and overfished occurrence.

Chapter Five

DISCUSSION

5. Discussion

The analysis in the present study was based on the surplus production models (Schaefer and Fox) where catch and effort (Unit $\approx 200\text{m}^2$ SBN/day) data of inland fish and small shrimp were applied to estimate the MSY of the Pasur River fishery.

The estimation of MSY based on Schaefer model in inland fish was 4.66 kg and optimum effort was 12.49 units. In Fox model, the MSY was 4.61 kg and optimum effort was 13.51 units. Similarly in small shrimp, the MSY in Schaefer model was 4.50 kg and optimum effort was 10.71 units. In Fox model, the MSY was 4.46 kg and optimum effort was 9.48 units.

In this study, MSY and f_{msy} based on Fox model were considered. According to Beverton and Holt, the Fox model is more suitable for estimating MSY and f_{msy} as the model provides a better fit to data than the Schaefer Model (*Introduction to tropical fish stock assessment* by Sparre and Siebren C. Venema (1998)). The range of average catch in inland fish was 3.45-6.62 kg corresponding to MSY (4.61 kg) and small shrimp was 2.85-5.08 kg corresponding to MSY (4.46 kg). This result indicates that the fish catch was higher than MSY in few months like January, February, March, June, July and December for inland fish and February, March, June, October and December for small shrimp. The Pasur River fishery was therefore overexploited in these months and it requires some effective management measures for those months maintain sustainable exploitation of the stocks by reducing fishing effort in the area. Moreover, this result was also similar in deterministic method for both fisheries. In this method, the same management measures were taken and continued for several months to reduce fish overexploitation.

Kalhor (2013) *et al.*, Siyal (2013) *et al.*, and Memon (2015) *et al.* reported that Maximum Sustainable Yield (MSY) of Bombay duck (*Harpodon neherus*), Silver pomfret (*Pampus argenteus*) and Barramundi (*Lates calcarifer*) fishery from Pakistan were estimated for Schaefer and Fox models with three different error assumptions of normal, log-normal and gamma by using CEDA and ASPIC computer softwares. They suggested that the estimated values of MSY were smaller than the recent catch which indicated that this fishery in Northern Arabian Sea was overexploited and required some effective management measures and maintaining sustainable exploitation of the stocks by reducing fishing effort in the area. Implementing conservation of an excellent food fish was also required there. Mehanna (2004) applied the surplus production model of Schaefer (1954 and 1957) to estimate MSY and f_{msy} and estimated that the stocks of

round herring and slimy mackerel in the Gulf of Suez were overexploited. According to Mehanna (2004), $2/3 f_{msy}$ as a target reference point was safer than the use of the limiting reference point (f_{msy}). Garcia (1989) *et al.* suggested estimating maximum sustainable yield (MSY) using Schaefer and Fox model and setting a level of f_{msy} (or $2/3$ MSY) if the stock is already being exploited at a relatively high level. According to Jong (2001) and Hong (2008), the estimation of MSY by using Schaefer model in southwestern part of Taiwan for Sergestid shrimp was 865 ton and 749 ton and according to Chen (1999) & Hong (2008) it was 876 ton and 732 ton respectively using Fox model. They reported that the Sergestid shrimp fishery in Tongkang waters is at a reasonable exploitation level (experience no overfishing and overfished occurrence).

All the biological statistical data or results possess some sort of uncertainty and the estimated MSY in present work does too. However, no evidence can either accept or reject this hypothesis. To clarify this problem, a suitable stock identification study with molecular technique such as DNA analysis will be needed in the future. Similar estimation of MSY and TAC was found from the deterministic and stochastic methods.

In deterministic method, the results for inland fish suggested that the observed CPUE was higher in January, February, March, July and December than the estimated CPUE. In these few months the catch should be reduced and fisheries management measures should be applied. In addition, two biological reference points C/MSY (for few months like January, February, March, June, July and December) and f_t/f_{msy} (for December) which refer that these species are overfishing and they were suggesting that TAC should be maintained for these species. In stochastic method, the means MSY, TAC, and f_{msy} with 95% CI for inland fish were estimated to be 4.53 (4.52-4.54) kg, 4.08 (4.07-4.09) kg, and 13.22 (13.15-13.29) units respectively. The stochastic results suggested that the mean of MSY (4.53 kg) was higher than TAC (4.08 kg) and it indicates that if the TAC is fully utilized for this fish species, it will ensure a long-term sustainability of this stock in spite of no overfishing and overfished occurrence.

Similarly the results for small shrimp suggested that the observed CPUE was higher in February, March, June, October and December than the estimated CPUE. In these few months, the catch should be reduced and effective fisheries management measures should be taken and continued. In addition, two biological reference points C/MSY (for few months like February, March, June, October and December) and f_t/f_{msy} (all months) imply that this species was overfishing and



Chapter Six

CONCLUSION

6. Conclusion

MSY (Schaefer and Fox models), f_{msy} and TAC for inland fish and small shrimp in the Pasur River fishery is estimated based on four years of average catch and effort data from the Department of Fisheries. Considering the estimated MSY and f_{msy} the inland fish are overexploited in the months of January, February, March, June, July, October, November and December and small shrimp are overexploited in the months of January, February, March, May, June, September, October, November and December. TAC is also estimated in this study to reduce the fishing effort for rational exploitation in the above mentioned months. A limited number of records (monthly average of four years) are considered in this study which is not sufficient for a reliable MSY. A long time records (around 10 years) may provide a suitable MSY for river fisheries. However, the study can be a milestone to progress the population dynamics based work in the Pasur River.

Chapter Seven

REFERENCES

7. References

- Brodziak, J. and Ishimura, G., 2010. Production model analyses of maximum sustainable yield-based reference points for the North Pacific swordfish stocks. Workshop report, Billfish working group international Scientific Committee, Victoria, British Columbia, Canada, pp. 4.
- Brussels, 2012. Reasons to achieve and move beyond Maximum sustainable yield. Report, Web: www.oceana.org (Oceana). pp. 4.
- Brussels, 2006. Communication from the Commission to the Council and the European Parliament: Implementing sustainability in EU fisheries through maximum sustainable yield. pp. 2.
- Caddy, J. F., 1980. Surplus production model. *In*: Selected lectures from the CIDA/FAO/CECAF seminar on fishery resource evaluation. pp. 29-45.
- Chakraborty, S. K., Deshmukh, V. D., Khan, M. Z., Vidyasagar, K. and Raje, S. G., 1997. Estimates of growth, mortality, recruitment pattern and maximum sustainable yield of important fishery resources of Maharashtra coast. *Indian journal of Marine sciences*, 26: 53-56.
- Chantarasri, S., 1994. Integrated resource development of the sundarbans reserved forest Bangladesh. Food and Agriculture Organization of the United Nations. BGD/84/056: 172.
- Die, D. J. and Caddy, J. F., 1997. Sustainable yield indicators from biomass: are there appropriate reference points for use in tropical fisheries. *Fisheries Research*, 32: 69-79.
- DoF. 2015. National Fish Week 2015 Compendium (In Bengali). Department of Fisheries, Ministry of Fisheries and Livestock, Bangladesh. pp. 1-148.
- Elawad, A. N., 2014. Maximum sustainable yield, swept area and biomass of some biota from the Southern trawlable areas, Red Sea, Sudan. *Global Research Journal of Fishery Science and Aquaculture*: Vol. 1(4): 017-020.

- FAO. 2012. The State of World Fisheries and Aquaculture. Fisheries and Aquaculture Department (<http://www.fao.org>). pp. 209.
- Fox, W. W. Jr., 1970. An exponential surplus yield model for optimizing exploited fish populations. *Trans. Am. Fish. Soc.*, 99: 80-88.
- Froese, R., Stern-Pirlot, A., Winker, H. and Gascuel, D., 2008. Size matters: how single-species management can contribute to ecosystem-based fisheries management. *Fisheries Research*, 92: 231-241.
- Gaertner, D., Fonteneau, A. and Laloe, F., 2000. Approximate estimate of the maximum sustainable yield from catch data without detailed effort information: application to tuna fisheries. *Aquatic Living Resource*, 14: 1-9.
- Gecek, S., Legovic, T. and Klanjscek, J., 2010. Maximum sustainable yield and species extinction in ecosystems. *Ecological Modelling*, 221: 1569-1574.
- Garcia, S., Sparre, P. and Csirke, J., 1989. Estimating Surplus Production and Maximum Sustainable Yield from Biomass Data when Catch and Effort Time Series are not available. *Fisheries Research*, 8: 13-23.
- Gulati, D. K., 2007. Analysis of Survey of *Nemipterus Japonicus* Found along the west coast of india. P.O. Box 1390, Skulagata 4, 120 Reykjavik, Iceland, pp. 35.
- Gulland, J. A., 1971. The Fish Resources of the Ocean. Fishing News (Books), West By fleet. pp. 255.
- Gulland, J. A., 1983. Fish stock assessment: a manual of basic methods. Chichester, U.K., Wiley Inter science, FAO/Wiley series on food and agriculture, (1): pp. 223.
- Haddon, M., 2001. Modelling and Quantitative Methods in Fisheries, Chapman & Hall/CRC, New York, pp. 406.
- Hilborn, R. and Walters, C. J., 2002. Quantitative fisheries stock assessment: Choice, dynamics and uncertainty. Chapman and Hall, Inc., New York: pp. 570.
- Jana, S. and Ghose, A., 2013. Bio-economic Analysis of Marine Fish Production in West Bengal. *Journal of Economics and Sustainable Development*, Vol.4, No.14: 54-61.
- Larkin, P., 1977. An epitaph for the concept of the maximum sustained yield. *Transactions of the American Fisheries Society*, 106: 1-11.
- Lavania-Baloo, Kikuchi, A. and Azman, S., 2012. Approach of Maximum Sustainable Yield (MSY) Concept to Design a Sustainable Phytoremediation System to Improve Shrimp Pond Water Quality. *World Applied Sciences Journal*, 17 (4): 452-457.
- Ludwig, D. and Walters, C. J., 1989. "A robust method for parameter estimation from catch and effort data," *Canadian Journal of Fisheries and Aquatic Science*, Vol. 46: 137-144.
- Ludwig, D., Walters, C. J., and Cooke, J., 1988. "Comparison of two models and two estimation methods for catch and effort data," *Natural Resource Modelling*, Vol. 2: 457-498.
- Lugten, G. and Andrew, N., 2008. Maximum Sustainable Yield of Marine Capture Fisheries in Developing Archipelagic States— Balancing Law, Science, Politics and Practice. *The International Journal of Marine and Coastal Law*, 23: 1-37.
- Mainardi, S., 2010. Maximum Sustainable Yields and Non-linear Paths to Steady-state Equilibrium. *Marine Resource Economics*, 25: 185-212.

- Mehanna, S. F., 2004. Maximum Sustainable yield of the Round herring, *Etrumeus Teres* and Slimy mackerel, *Scomber Japonicus* in the Gulf of Suez. *Egyptian journal of aquatic research*, 30: 322-325.
- Memon, K.H., Liu, Q., Kalhor, M.A., Nabi, A. and KU, Z., 2015. Maximum sustainable yield estimates of the Barramundi *Lates calcarifer* fishery from Northern Arabian Sea. *Indian Journal of Geo- Marine Sciences*, Vol. 44(1): 7.
- Miao, S., Jong, J., and Cheng, T. H., 2006. "Economic analysis on management of TAC regarding Sakura shrimp fishery," *Journal of the Fisheries Society of Taiwan*, Vol. 33(1): 35-43.
- Mueter, F. J. and Megrey, B. A., 2006. Using multi-species surplus production models to estimate ecosystem-level maximum sustainable yields. *Fisheries Research*, 81: 189-201.
- Pope, J. G., 1983. Fisheries Resource Management Theory and Practice. In: Taylor, J. L. and Baird, G. G., (Eds.) *New Zealand finfish Fisheries: the Resources and their Management*. Trade Publications, Auckland. pp. 56-62.
- Pauly, D. and Munro, J. L., 1984. Once more on the comparison of growth in fish and invertebrates. *ICLARM Fishbyte*, 2 (1): 21.
- Pella, J. J. and Tomlinson, P. K., 1969. "A generalized stock production model," *IATTC Bulletin Inter-American Tropical Tuna Commission*, Vol. 13: 419-496.
- Polacheck, T., Hilborn, R., and Punt, A. E., 1993. "Fitting surplus production models: Comparing methods and measuring uncertainty," *Canadian Journal of Fisheries and Aquatic Science*, Vol. 50: 2597-2607.
- Puthy, E. M., 2007. Marine Fisheries Resource Management Potential for Mackerel Fisheries of Cambodia. Fisheries training programme. P.O. Box 1390, Skulagata 4, 120 Reykjavik, Iceland. pp. 65.
- Ricker, W. F., 1975. Computation and interpretation of biological statistics of fish populations. *Bull. Fish. Res. Board Can.*, 191: pp. 382.

- Russell, E. S., 1931. "Some theoretical considerations on the 'overfishing' problem" *Journal de Conseil International pour l'Exploration de la mer*, 6: 1-20.
- Rothschild, B. J. and Jiao, Y., 2013. Comparison between Maximum Sustained Yield Proxies and Maximum Sustained Yield Proxies and Maximum Sustained Yield. *The Open Fish Science Journal*, 6: 1-9.
- Sathianandan, T. V., Jayasankar, J., Vivekanandan, E., and Pillai N. G. K., 2008. Estimates on potential yield and maximum sustainable fleet size for marine fisheries in Kerala. *J. Mar. Biol. Ass. India*, 50 (2) : 196 – 201.
- Schaefer, M. B., 1954. Some aspects of the dynamics of populations, important for the management of the commercial fisheries. *Bull. Inter-American Trop. Tuna Comm.*, (1): 25-56.
- Schnute, J., 1977. "Improved estimates from the Schaefer production model: Theoretical considerations," *Journal of the Fisheries Research Board of Canada*, Vol. 34: 583-603.
- Siyal, F. K., Li, Y., Gao, T. and Liu, Q., 2013. Maximum Sustainable Yield Estimates of Silver Pomfret, *Pampus argenteus* (Family: Strometidae) Fishery in Pakistan. *Pakistan J. Zool.*, Vol. 45(2): 447-452.
- Sparre, P. and Venema, S. C., 1998. Introduction to tropical fish stock Assessment. *FAO Fisheries Technical Paper*, Vol. 306, No (1): 1-407.
- Walters, C. and Maguire, J., 1996. "Lessons for stock assessment from the northern cod collapse", *Reviews in Fish Biology and Fisheries*, 6: 125–137.
- Wu, C. C., Ou, C. H., Tsai, W. P. and Liu, K. M., 2010. Estimate of the Maximum Sustainable yield of Sergestid Shrimp in the waters off Southwestern Taiwan. *Journal of Marine Science and Technology*, 18(5): 652-658.

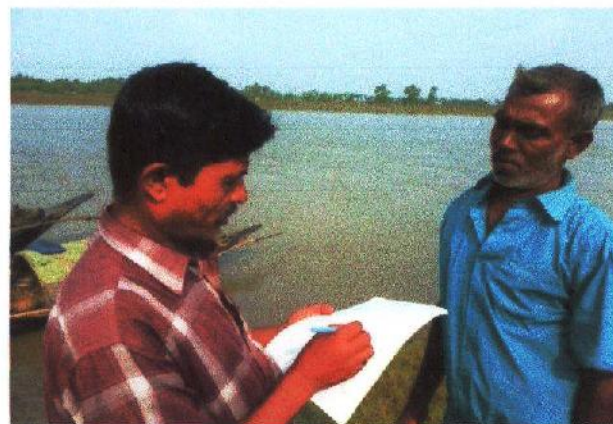
Chapter Eight

APPENDIXES

Appendix- 1: Photo Albums



Fishermen use set bag net to catch fish



Data collection process from fishermen in the Pasur River



After catching fish the accumulation of net



Fill up catch assessment form after catching fish

Appendix- 2: Catch Assessment Form

GOVERNMENT OF THE PEOPLE'S REPUBLIC OF BANGLADESH

DEPARTMENT OF FISHERIES

FISHERIES RESOURCES SURVEY SYSTEM

CATCH ASSESMENT SURVEY

Sample Catch Record



1. River Code:

2. District Code:

3. Upazilla

4. Union

5. Village Code:

8. Types of gear used Code:

6. Date: Day Month Year

7. Survey Officer's Name:

9. No. of fishing units operated:

10. No of sample units:

11. Encircle number observed	1	2	3	4	5	
12. Name of the head fisherman						
13. Number of fishermen on the boat						
14. Local name of gear used						
15. Catch in number and weight	No. Kg	No. Kg	No. Kg	No. Kg	No. Kg	Production price in Tk/kg
(01) Major Carp (Ruhi, Catla, Mrigel)						
(02) Other Carp (Kalbasu, Ghania, Kalia)						
(03) Catfish (Aire, Boal, Panges Rita, Silon)						
(04) Snake Head (Shol, Gazar, Taki)						
(05) Live fish (Koi, Singi, Margur)						
(06) Other Inland Fish (Chapila, Bacha, Phali, Poa)						
(07) Hilsa, Illish						
(08) Bombay Duck (lotia)						
(09) Indian Salmon (Lakhya)						
(10) Pomfret (Rup Chanda, Foli Chanda, Hali Chanda)						
(11) Sharks and rays (Hungor)						
(12) Others marine fish (Chhuri, Topposi, Chela etc)						
(13) Galda Shrimp						
(14) Bagda Shrimp						
(15) Other Big Shrimp (10 cm+)						
(16) Other Small Shrimp (less than 10 cm)						
(17) Crab						
Total						

Appendix- 3:

Table: Comparison of estimated parameters for the pasur river fishery

Species wise	Estimation of some parameters			
	Schaefer model		Fox model	
	MSY	f_{msy}	MSY	f_{msy}
Inland Fish	4.66	12.49	4.61	13.51
Small Shrimp	4.50	10.71	4.46	9.48
Catfish	1.62	17.57	1.55	21.28
Pomfret	1.45	34.08	-0.29	-20.62
Bornbay Duck	-0.39	4.40	-0.01	-3.07
Other Big Shrimp	-0.59	4.27	-0.41	-16.61
Other Marine Fish	0.63	12.63	2.38	125
Other carp	0.00	-0.26	2.95	26.73
snake fish	0.63	8.38	0.903	5.05
Live fish	0.54	8.21	-0.004	-2.94
Hilsha	0.01	8.05	-0.133	-5.423
Indian salmon	0.22	6.52	-0.022	-3.29
Sharks and Rays	-0.05	5.12	-0.003	0.81
Galda	-0.39	5.48	-0.35	1.21
Bagda	0.97	7.49	7.15	0.72
Crab	-0.50	5.32	2.76	4.98

**Unit= $\approx 200m^2$ SBN/day, f_{msy} = Optimum effort, MSY= Maximum sustainable yield.

Appendix-4:

Table-7: Estimation of mean MSY, f_{msy} and TAC from Monte Carlo simulations for inland fish

Replicate	Mean of MSY	STD. DEV (σ) $=(\bar{x}-x)^2$	Mean of f_{msy}	STD. DEV (σ) $=(\bar{x}-x)^2$	TAC	STD. DEV (σ) $=(\bar{x}-x)^2$
	4.48	0.0025	12.75	0.0225	4.05	0.0009
	4.60	0.0049	12.85	0.0025	4.15	0.0049
	4.57	0.0016	12.74	0.0256	4.13	0.0025
	4.47	0.0036	12.90	0	4.03	0.0025
	4.50	0.0009	13.00	0.01	4.04	0.0016
	4.51	0.0004	12.91	1E-04	4.05	0.0009
	4.54	1E-04	12.84	0.0036	4.08	0
	4.60	0.0049	13.10	0.04	4.15	0.0049
	4.55	0.0004	12.83	0.0049	4.09	1E-04
	4.59	0.0036	13.09	0.0361	4.13	0.0025
	4.53	0	12.88	0.0004	4.10	0.0004
	4.57	0.0016	12.96	0.0036	4.12	0.0016
	4.61	0.0064	12.99	0.0081	4.15	0.0049
	4.62	0.0081	13.40	0.25	4.18	0.01
	4.51	0.0004	13.32	0.1764	4.06	0.0004
	4.67	0.0196	12.94	0.0016	4.21	0.0169
	4.46	0.0049	12.98	0.0064	4.03	0.0025
	4.50	0.0009	13.11	0.0441	4.08	0
	4.57	0.0016	13.35	0.2025	4.12	0.0016
	4.65	0.0144	13.20	0.09	4.17	0.0081
	4.61	0.0064	13.00	0.01	4.16	0.0064
	4.60	0.0049	13.39	0.2401	4.15	0.0049
	4.49	0.0016	13.50	0.36	4.04	0.0016



24	4.60	0.0049	13.40	0.25	4.15	0.0049
25	4.54	1E-04	13.25	0.1225	4.11	0.0009
26	4.48	0.0025	13.29	0.1521	4.04	0.0016
27	4.51	0.0004	13.30	0.16	4.07	1E-04
28	4.45	0.0064	13.43	0.2809	4.01	0.0049
29	4.53	0	13.45	0.3025	4.09	1E-04
30	4.63	0.01	13.46	0.3136	4.18	0.01
31	4.59	0.0036	13.2	0.09	4.13	0.0025
32	4.48	0.0025	13.46	0.3136	4.05	0.0009
33	4.57	0.0016	12.97	0.0049	4.11	0.0009
34	4.50	0.0009	13.41	0.2601	4.06	0.0004
35	4.53	0	13.29	0.1521	4.09	1E-04
36	4.44	0.0081	13.24	0.1156	4.04	0.0016
37	4.47	0.0036	13.37	0.2209	4.02	0.0036
38	4.50	0.0009	13.39	0.2401	4.03	0.0025
39	4.48	0.0025	12.93	0.0009	4.04	0.0016
40	4.44	0.0081	13.26	0.1296	4.00	0.0064
41	4.40	0.0169	13.37	0.2209	3.98	0.01
42	4.49	0.0016	13.27	0.1369	4.04	0.0016
43	4.54	1E-04	12.89	1E-04	4.13	0.0025
44	4.49	0.0016	13.20	0.09	4.03	0.0025
45	4.61	0.0064	13.29	0.1521	4.15	0.0049
46	4.46	0.0049	13.37	0.2209	4.02	0.0036
47	4.52	0.0001	13.49	0.3481	4.04	0.0016
48	4.41	0.0144	13.46	0.3136	3.97	0.0121
49	4.48	0.0025	13.40	0.25	4.05	0.0009
50	4.50	0.0009	13.51	0.3721	4.04	0.0016
51	4.50	0.0009	13.42	0.2704	4.04	0.0016
52	4.53	0	13.35	0.2025	4.13	0.0025
53	4.49	0.0016	13.30	0.16	4.06	0.0004
54	4.45	0.0064	13.35	0.2025	4.06	0.0004
55	4.62	0.0081	12.96	0.0036	4.16	0.0064
56	4.58	0.0025	13.00	0.01	4.14	0.0036
57	4.46	0.0049	13.27	0.1369	4.00	0.0064
58	4.40	0.0169	13.46	0.3136	3.95	0.0169
59	4.53	0	13.49	0.3481	4.14	0.0036
60	4.43	0.01	13.36	0.2116	3.97	0.0121
61	4.48	0.0025	13.41	0.2601	4.05	0.0009
62	4.46	0.0049	13.29	0.1521	3.97	0.0121
63	4.44	0.0081	13.10	0.04	4.01	0.0049
64	4.60	0.0049	12.93	0.0009	4.15	0.0049
65	4.47	0.0036	13.17	0.0729	4.03	0.0025
66	4.43	0.01	13.10	0.04	4.00	0.0064
67	4.54	1E-04	13.14	0.0576	4.13	0.0025
68	4.63	0.01	13.17	0.0729	4.18	0.01
69	4.58	0.0025	13.39	0.2401	4.12	0.0016
70	4.50	0.0009	13.34	0.1936	4.04	0.0016
71	4.48	0.0025	13.46	0.3136	4.03	0.0025
72	4.65	0.0144	13.49	0.3481	4.15	0.0049
73	4.47	0.0036	13.41	0.2601	4.05	0.0009
74	4.50	0.0009	12.84	0.0036	4.05	0.0009
75	4.63	0.01	12.96	0.0036	4.18	0.01
76	4.44	0.0081	13.18	0.0784	4.01	0.0049
77	4.59	0.0036	13.38	0.2304	4.14	0.0036
78	4.62	0.0081	13.45	0.3025	4.17	0.0081
79	4.60	0.0049	13.48	0.3364	4.15	0.0049
80	4.51	0.0004	12.87	0.0009	4.06	0.0004
81	4.48	0.0025	12.96	0.0036	4.07	1E-04
82	4.66	0.0169	12.99	0.0081	4.16	0.0064
83	4.53	0	13.07	0.0289	4.09	1E-04
84	4.49	0.0016	13.24	0.1156	4.06	0.0004
85	4.59	0.0036	13.26	0.1296	4.14	0.0036
86	4.51	0.0004	13.36	0.2116	4.03	0.0025
87	4.56	0.0009	13.47	0.3249	4.10	0.0004
88	4.45	0.0064	13.36	0.2116	3.94	0.0196
89	4.59	0.0036	13.49	0.3481	4.12	0.0016

90	4.44	0.0081	13.52	0.3844	4.01	0.0049
91	4.61	0.0064	13.39	0.2401	4.12	0.0016
92	4.51	0.0004	13.06	0.0256	4.01	0.0049
93	4.63	0.01	13.19	0.0841	4.15	0.0049
94	4.40	0.0169	13.32	0.1764	3.92	0.0256
95	4.55	0.0004	12.97	0.0049	4.08	0
96	4.62	0.0081	13.44	0.2916	4.14	0.0036
97	4.41	0.0144	13.41	0.2601	4.00	0.0064
98	4.49	0.0016	13.23	0.1089	4.05	0.0009
99	4.40	0.0169	12.90	0	4.02	0.0036
100	4.53	0	13.15	0.0625	4.09	1E-04
Total	452.50	$\sigma = 0.0688$	1321.68	$\sigma = 0.3826$	407.76	$\sigma = 0.0631$
	Mean = 4.53		Mean = 13.22		Mean = 4.08	

Appendix-5:

Table-12: Estimation of mean MSY, f_{msy} and TAC from Monte Carlo simulations for small shrimp.

Replicate	Mean of MSY	STD. DEV (σ) $=(\bar{x}-x)^2$	Mean of f_{msy}	STD. DEV (σ) $=(\bar{x}-x)^2$	TAC	STD. DEV (σ) $=(\bar{x}-x)^2$
1	4.45	0.0009	9.50	0.01	4.00	0.0004
2	4.35	0.0049	9.33	0.0049	3.92	0.0036
3	4.40	0.0004	9.45	0.0025	3.96	0.0004
4	4.46	0.0016	9.36	0.0016	4.01	0.0009
5	4.38	0.0016	9.40	0	3.94	0.0016
6	4.39	0.0009	9.46	0.0036	3.95	0.0009
7	4.42	0	9.38	0.0004	3.98	0
8	4.48	0.0036	9.35	0.0025	4.03	0.0025
9	4.43	1E-04	9.39	1E-04	3.99	0.0001
10	4.47	0.0025	9.43	0.0009	4.02	0.0016
11	4.41	1E-04	9.39	1E-04	3.97	1E-04
12	4.45	0.0009	9.42	0.0004	4.00	0.0004
13	4.48	0.0036	9.40	0	3.95	0.001
14	4.50	0.0064	9.41	1E-04	3.98	0
15	4.39	0.0009	9.33	0.0049	3.95	0.0009
16	4.35	0.0049	9.39	1E-04	4.10	0.0144
17	4.34	0.0064	9.46	0.0036	3.88	0.01
18	4.38	0.0016	9.41	1E-04	4.05	0.0049
19	4.35	0.0049	9.43	0.0009	4.09	0.0121
20	4.53	0.0121	9.34	0.0036	3.97	1E-04
21	4.39	0.0009	9.49	0.0081	3.96	0.0004
22	4.48	0.0036	9.43	0.0009	3.98	0
23	4.37	0.0025	9.37	0.0009	4.01	0.0009
24	4.48	0.0036	9.34	0.0036	4.08	0.01
25	4.42	0	9.50	0.01	4.04	0.0036
26	4.46	0.0016	9.43	0.0009	3.94	0.0016
27	4.49	0.0049	9.39	1E-04	3.91	0.0049
28	4.39	0.0009	9.38	0.0004	4.05	0.0049
29	4.41	1E-04	9.44	0.0016	4.01	0.0009
30	4.51	0.0081	9.47	0.0049	4.05	0.0049
31	4.47	0.0025	9.46	0.0036	4.02	0.0016
32	4.36	0.0036	9.47	0.0049	3.93	0.0025
33	4.45	0.0009	9.40	0	4.00	0.0004
34	4.38	0.0016	9.35	0.0025	3.96	0.0004
35	4.51	0.0081	9.42	0.0004	4.06	0.0064
36	4.42	0	9.36	0.0016	4.01	0.0009
37	4.35	0.0049	9.39	1E-04	3.99	0.0001
38	4.48	0.0036	9.46	0.0036	3.95	0.0009

39	4.46	0.0016	9.42	0.0004	4.07	0.0081
40	4.42	0	9.42	0.0004	3.97	1E-04
41	4.34	0.0064	9.38	0.0004	4.00	0.0004
42	4.47	0.0025	9.35	0.0025	4.04	0.0036
43	4.52	0.01	9.42	0.0004	4.10	0.0144
44	4.40	0.0004	9.44	0.0016	3.98	0
45	4.36	0.0036	9.47	0.0049	3.94	0.0016
46	4.39	0.0009	9.37	0.0009	3.99	0.0001
47	4.50	0.0064	9.31	0.0081	4.04	0.0036
48	4.39	0.0009	9.46	0.0036	3.99	0.0001
49	4.36	0.0036	9.49	0.0081	3.94	0.0016
50	4.46	0.0016	9.38	0.0004	4.07	0.0081
51	4.43	1E-04	9.42	0.0004	4.01	0.0009
52	4.51	0.0081	9.40	0	4.09	0.0121
53	4.47	0.0025	9.30	0.01	4.07	0.0081
54	4.43	1E-04	9.32	0.0064	4.03	0.0025
55	4.45	0.0009	9.48	0.0064	3.95	0.0009
56	4.50	0.0064	9.46	0.0036	4.03	0.0025
57	4.34	0.0064	9.38	0.0004	3.97	1E-04
58	4.38	0.0016	9.36	0.0016	3.92	0.0036
59	4.51	0.0081	9.34	0.0036	4.02	0.0016
60	4.37	0.0025	9.28	0.0144	3.88	0.01
61	4.46	0.0016	9.48	0.0064	3.93	0.0025
62	4.34	0.0064	9.46	0.0036	3.94	0.0016
63	4.42	0	9.46	0.0036	4.04	0.0036
64	4.38	0.0016	9.36	0.0016	3.89	0.0081
65	4.45	0.0009	9.39	1E-04	4.00	0.0004
66	4.41	1E-04	9.45	0.0025	3.97	1E-04
67	4.52	0.01	9.40	0	3.95	0.0009
68	4.38	0.0016	9.40	0	3.94	0.0016
69	4.45	0.0009	9.36	0.0016	3.99	0.0001
70	4.48	0.0036	9.32	0.0064	4.09	0.0121
71	4.46	0.0016	9.40	0	4.04	0.0036
72	4.38	0.0016	9.48	0.0064	4.06	0.0064
73	4.45	0.0009	9.45	0.0025	4.07	0.0081
74	4.38	0.0016	9.42	0.0004	4.00	0.0004
75	4.41	1E-04	9.46	0.0036	3.99	0.0001
76	4.42	0	9.34	0.0036	4.03	0.0025
77	4.37	0.0025	9.35	0.0025	3.94	0.0016
78	4.50	0.0064	9.38	0.0004	3.86	0.0144
79	4.38	0.0016	9.37	0.0009	3.97	1E-04
80	4.39	0.0009	9.41	1E-04	3.94	0.0016
81	4.46	0.0016	9.53	0.0169	4.04	0.0036
82	4.44	0.0004	9.37	0.0009	3.92	0.0036
83	4.51	0.0081	9.38	0.0004	4.05	0.0049
84	4.47	0.0025	9.35	0.0025	4.03	0.0025
85	4.43	1E-04	9.42	0.0004	3.99	0.0001
86	4.49	0.0049	9.40	0	4.10	0.0144
87	4.39	0.0009	9.43	0.0009	3.91	0.0049
88	4.43	1E-04	9.39	1E-04	3.92	0.0036
89	4.47	0.0025	9.31	0.0081	4.06	0.0064
90	4.42	0	9.34	0.0036	4.03	0.0025
91	4.39	0.0009	9.46	0.0036	4.04	0.0036
92	4.49	0.0049	9.38	0.0004	4.08	0.01
93	4.41	1E-04	9.48	0.0064	3.97	1E-04
94	4.38	0.0016	9.44	0.0016	3.89	0.0081
95	4.43	1E-04	9.41	1E-04	4.04	0.0036
96	4.33	0.0081	9.39	1E-04	3.89	0.0081
97	4.29	0.0169	9.42	0.0004	3.99	0.0001
98	4.47	0.0025	9.38	0.0004	3.91	0.0049
99	4.28	0.0196	9.43	0.0009	4.02	0.0016
100	4.41	1E-04	9.41	1E-04	4.02	0.0016
Total	442.51	$\sigma = 0.0552$	940.49	$\sigma = 0.0511$	399.33	$\sigma = 0.0586$
	Mean = 4.43		Mean = 9.40		Mean = 3.99	