SUSTAINABLE FISHERIES MANAGEMENT PROJECT (SFMP)

Training Course Curriculum on Fish Stock Assessment Methods

Summary

JULY, 2015

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Cover photo: Ghana fisheries landing sit

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Acronyms

BDM	Biomass Dynamic Model
BMSY	Biomass that produces a Maximum Sustainable Yield
FC	Fisheries Commission
FMSY	Fishing Mortality that produces Maximum Sustainable Yield
GoG	Government of Ghana
MOFAD	Ministry of Fisheries and Aquaculture Development
M	Natural Mortality
MSY	Maximum Sustainable Yield
SFMP	Sustainable Fisheries Management Program
SR	Stock Recruitment
SSB	Stock Spawning Biomass
URI	University of Rhode Island
USAID	United States Agency for International Development
YPR	Yield Per Recruit
VPA	Virtual Population Analysis

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SECTION 1: INTRODUCTION

The Sustainable Fisheries Management Project (SFMP) conducted two training sessions fish stock assessment. In each session, participants from the Fisheries Commission, Ministry of Fisheries and Aquaculture Development, Fisheries Scientific and Survey Division, Division of Water Resources, University of Cape Coast and local NGOs attended the training. Each training session was for one-week covering several mathematical and statistical methods, computer data analysis and fish stock assessment methods and models. The goal of the training focused on capacity building of the Fisheries Commission and project partners in applied techniques to stock assessment and prepare participants to interpret the results and apply it to fisheries management. Working in teams, participants obtained a wide range of assessment tools focused on data and information on small pelagic fisheries of Ghana. The training used a range of methods including lectures, exercises, small group work, simulations and case studies to create a robust interactive and dynamic environment and learn new insights and skills in fish stock assessment. At the end of the course, participants were able to conduct single species assessment methods and understand data collection needs for different assessment methods. Participants developed indicators and references points, both biological and economic, as tools in fisheries management, knowledge of fishery population and fishery processes by using simulation models to improve scientific advice for managers. Participants were able to run their own stock assessment model by end of the training, interpret data and made summaries for managers.

The format of the training was divided into three sessions for each topic; a lecture to introduce and explain the topic followed with questions and answers, then a group discussion and "help your peer" session where participants helped each other in an informal setting to clarify and discuss among themselves the issues and questions. The third session was the practical and hand-on exercise using excel spreadsheets, NOAA stock assessment tool box and programs in R. Participants were provided with real data of local context and were asked to analyze them and fit the appropriate model and interpret the results. Teams were asked to prepare a fisheries management recommendations and the monitoring and evaluation techniques for impact assessment. The instructor presented the solution step by step and allowed for group discussions.

The Material used in the training were drawn from Atlantic States Marine Fisheries Commission, the class lectures of Najih Lazar and Laura Skrobe, notes of Dr. Joseph T. DeAlteris, Professor of Fisheries and Aquaculture, University of Rhode Island and the Malcom Haddon's book "Modelling and quantitative methods in fisheries".

The training sessions (introduction and advanced) were delivered by Najih Lazar, Senior Fisheries Advisor of SFMP. We present here a summary of the topics presented during the first workshop with an overview on fisheries management.

Recognizing that not all participants are trained/dedicated in mathematics and bio-statistics, the training was prepared excel spreadsheets and easy to follow instructions to fill in the information and run the models.

SECTION 2: FISH STOCK ASSESSMENT SYLLABUS

2.1 Introduction to stock assessment and fisheries management

- Why manage fisheries?
- General approaches to fisheries management (input/output controls)
- Biological reference points
- Contribution of fish stock assessment to appropriate fisheries management
- Fisheries and research surveys
- Effects of fishing on a population
- Maximum sustainable yield
- Fisheries management games

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- Formatting a worksheet
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- Spawning stock biomass per recruit
- Ricker yield per recruit
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- Length based cohort analysis
- Overview of ELEFAN

SECTION 3: STOCK ASSESSMENT AND FISHERIES MANAGEMENT: AN OVERVIEW

3.1 Stock Assessment

A fish population is a group of interbreeding fish that is characterized by its own birth rate, growth rate, age structure, and death rate. A fish stock is often referred to as that portion or subset of a fish population that is subject to exploitation or harvest. Fish stocks may respond differently to exploitation because of differences in reproductive, growth, and natural mortality rates. Therefore, fish stocks are considered discrete units for management purposes.

The purpose of fish stock assessment is to evaluate the status of a fish stock and to predict how the stock will respond to various exploitation or harvest scenarios. The current status of a stock is characterized by estimating stock parameters such as mortality (natural and fishing), abundance, biomass, age structure, and growth rate. The future status of a stock is predicted by modeling the process of stock change over time in response to management, using the previously estimated stock parameters.

Fisheries management is the process by which we attempt to control fish stock abundance by regulating harvest. Fisheries management decisions are made in an attempt to meet pre- determined objectives concerning future stock status based on biological, sociological, economic, and political inputs. The history of fish stock assessment and fishery resource management began with the erroneous assumption that the ocean's resources were unlimited. Thomas Huxley concluded in 1884 that fish were so abundant and fecund, and man's ability to harvest them was so limited, that fish populations were immune to man's activities. Shortly thereafter, at the turn of the century, the International Council for the Exploration of the Sea (ICES) initiated the collection of commercial catch data to respond to concerns of overfishing and depleted fish stocks. World Wars I and II allowed worldwide fish stocks to rebuild, but overfishing in the last fifty years has driven stocks to record low levels.

The most recent Report of the Food and Agriculture Organization (FAO) on the Status of fisheries indicates that 98 fish stocks globally are considered overfished. Fisheries managers have the responsibility to properly manage these fish stocks for the long-term benefit of both the fish stocks and the human population. Management decisions are made based on the best scientific information, derived through the various methods of fish stock assessment and analyses of population dynamics. Used properly, these methods guide managers to implement and monitor the effects of management measures to rebuild and will ensure harvest pressure does not exceed sustainable levels.

A stock assessment report typically includes the following sections:

- Description of the fisheries that interact with the stock and the presentation of fishery dependent data (landings, effort, etc.).
- Results of research surveys that provide fishery independent data on abundance and samples for biological analysis.
- Life history characteristics of the resource including natural mortality, growth, and maturity.
- Estimation of population and fishery parameters such as stock-recruitment relationships, exploitation rates, yield, and spawning stock biomass suing assessment models.
- Biological reference points based on the previous models and analyses, and an evaluation of the current status of the stock based on the reference points.
- Review of management objectives and alternative actions to achieve a sustainable fishery, and an evaluation of these alternatives using the models previously developed in a projection mode.

3.1.1 Fisheries Management

The Fisheries Act-625 of Ghana enacted in 2002, empowered the government to regulate fishing from 0 to 200 miles off the coasts of Ghana. The Act created a Fisheries Commission charged with the responsibility of developing fishery management plans (FMPs) for stocks within the EEZ. Commission members include representatives of fisheries associations, government ministries and research institutions. The Commission is led by an Executive Director who supervises five divisions to assist in the preparation of FMPs and management of fisheries.

The Fisheries Scientific Survey Division (FSSD) is mandated by the Act-625 to collect and analyze data on the status of the fishery resources off the coasts of Ghana and on the fisheries. FSSD then provides this information to the Fisheries Commission for their management recommendations. The Minister of MoFAD has the authority to authorize management rules and orders for the FC to implement them.

Additionally, the FC can assign special sub-committees or working groups to provide further technical assistance on scientific and sociological issues related to the FMPs. Rules for the development of FMPs are provided in the fisheries Act-625, and provide directions for the definition of overfishing, the establishment of measures to prevent overfishing, and the development of a program for rebuilding a stock if overfishing already exists. Public input and comment is sought throughout the FMP development process. There is no provision for plan amendments, however if conditions in the fishery are changing rapidly, Ministerial Executive Orders by public notices in the Gazette are used to allow management to keep pace with an evolving fishery.

The Fisheries Act 625 authorized issuance of legal regulations to give effect to the fisheries Act-625 through a legislative instrument of 1968, named Fisheries Regulation of 2010. They are intended to provide specific management rules pertaining fishing gear, vessels and fishing operation. However, there have been challenges with compliance and effective enforcement. A clear example is the enforcement operations that was conducted by a government enforcement task force which became a complete failure partly because the enabling conditions necessary to achieve the desired objectives of the operations were not planned carefully. One of the lessons learned that resource users need to be educated on the Fisheries Law and Regulations to promote voluntary compliance as a complementary measure to police enforcement.

Management strategies for controlling harvest rates include restricting effort, catch quotas, closed areas, etc. As we enter the twenty-first century, there is excess capacity or over-capitalization in all fisheries, resulting in overfishing of limited resources. To limit or restrict overfishing, management has responded in some fisheries by issuing controlled access, seasonal fisheries closure, area closure and/or annual total allowable catch (TAC). These quotas result in "derby fisheries" where individual fishermen attempt to catch as much as they can, until the quota is reached and the fishery closed. These derbies result in temporary market gluts and lower prices paid for catch to fishermen. Other methods to control fishing mortality include limiting effort by closing fishing areas during specific times to protect spawning aggregation of fish or nursery areas, allowing vessels only limited number of days at sea, restricting the vessel size, horsepower, or the amount of gear fished.

The most controversial effort-control measure, however, is limited entry. This is a fundamental change in the traditional open-access fishery management policies. Limited entry begins with a moratorium on new licenses. A related issue is the transferability of licenses, i.e., can an individual sell his license, or can potential new entrants to the fishery apply to a lottery to enter the fishery, as existing participants leave the fishery.

Another aspect of limited entry is the provision for property rights through individual transferable quotas (ITQ) or sector quotas. In individual quota fisheries, access to the fishery is controlled with a moratorium on new licenses, then fishermen are individually awarded a portion or allocation of the total allowable catch (TAC) each year, and that share may be transferable to other fishermen via direct sale. Thus larger, more efficient harvesters are able to purchase the shares of the smaller, less efficient harvesters. This results in consolidation of harvesting capacity and increased economies of scale. Typically, limits are placed on the total number of shares an individual or corporation may acquire so as to avoid monopoly situations. With the establishment of sectors that are provided "catch shares", groups of fishermen are provided a portion of the TAC, and the group of fishermen cooperatively work together to allocate individual portions of their TAC.

SECTION 4: ESTIMATION OF GROWTH PARAMETERS

4.1 Introduction

The prediction of the length or weight of an aquatic animal as a function of age is a critical aspect of fish stock assessment. The growth of a fish, crustacean, or mollusc is rapid at a young age, slows at middle age, and stops at old age. The growth of an individual animal can be quite variable depending on food supply, environmental conditions, and genetic background. Therefore, the analysis of the age and growth of an aquatic animal requires large sample sizes.

Von Bertalanffy (1938) proposed a simple asymptotic function or model to describe the growth of fish by length, (*i.e.*, a curve for which the slope continuously decreases with increasing age, approaching an upper asymptote parallel to the *x*-axis) (Figure 1). Curves of weight at age also approach an upper asymptote, but form an asymmetrical sigmoid shape with an inflection occurring at a weight equal to about one third of the asymptotic weight.

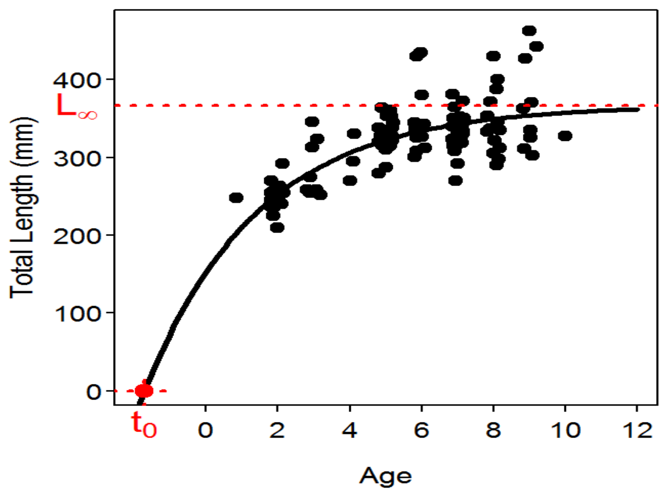

Figure 1: Example of typical parameterization of the VBGF fit to size-at-age

Fish measurements may include total length, fork length, depth, girth, width, and height. Weight measurements may include total body weight, wet weight, dry weight, organ weight, shell weight, and meat weight. Age can be determined by counting growth rings that form in fish hard parts including scales, otoliths, and fin spines. Growth rings result from seasonal variation in growth. Ages can also be inferred from multi-modal length-frequency distributions (e.g., for tropical fish species that exhibit little seasonal variation in growth and for some crustaceans) using graphical methods and computer based analysis.

The effect of the growth coefficient K on the growth curve for a given L_∞ is shown in Figure 2. A value of $K = 0.2$ results in a gently ascending curve, whereas a value of $K = 1.0$ results in a rapidly rising curve.

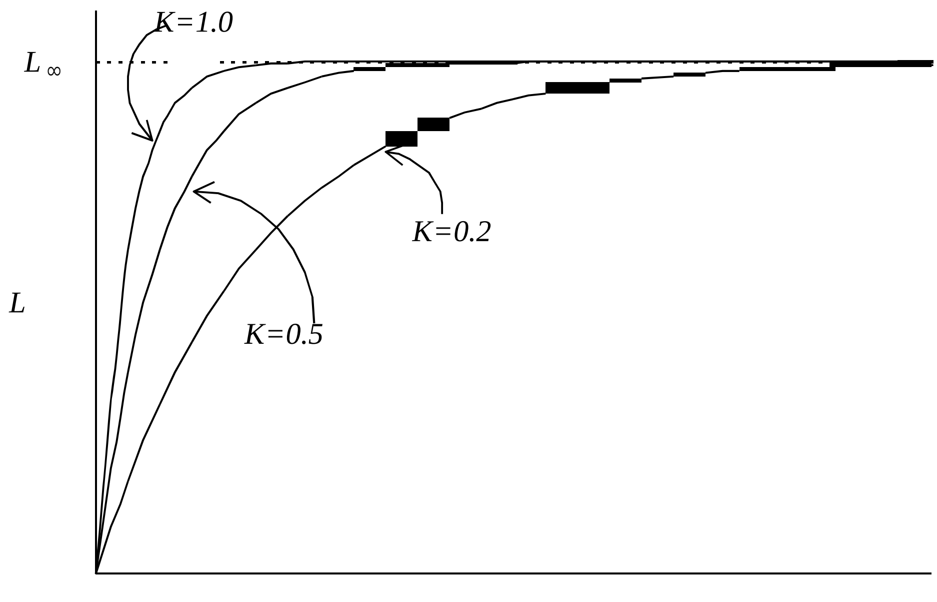

Figure 2: The effect of the value of the growth coefficient (K) on the growth curve.

4.2 Estimating Weight

The relation between the weight and length of an aquatic animal is expressed as:

$$W_t = aL_t^b$$

where a is a unit conversion coefficient

b is a volumetric expansion coefficient.

4.2.1 Estimating Growth Equation Parameters

There are several classical methods for estimating von Bertalanffy growth model parameters using linear regression techniques. The Gulland-Holt method, based on the original rate equation, assumes uniform growth over an interval between two ages and plots that growth increment against mean length between the two ages (Gulland and Holt 1959).

That is:

$$dL/dt = K(L_\infty - L_t)$$

or

$$\Delta L/\Delta t = KL_\infty - KL_t$$

which has the form of the linear model:

$$y = b + ax$$

where K = slope and L_∞ = y-intercept/K.

SECTION 5: ESTIMATION OF MORTALITY RATES

The general diagram of the dynamics of exploited fish stocks can be represented by an input-output diagram (Figure 3). Recruits into the stock and growth add to the total abundance and weight of the stock and are therefore considered inputs. Total losses from the stock are measured in two terms and are considered outputs. Natural mortality (M) is a measure of mortality resulting from natural causes (e.g., diseases, pollution, predation, aging), and fishing mortality (F) is a measure of mortality attributable to human harvest and discards.

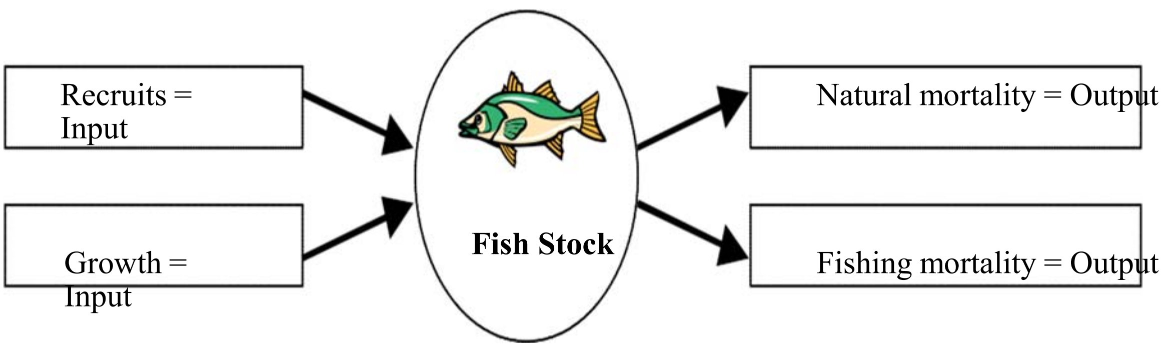

Figure 3: Schematic diagram of inputs and losses to a stock.

Mortality represents losses to a stock and is expressed as the rate of change of the size of a stock or a portion of the stock (e.g., cohort). It is generally most convenient to deal with instantaneous rates of change; *i.e.*, the rate at which the numbers in the population are decreasing. The term "instantaneous" infers that the number of fish that die in an “instant” is at all times proportional to the number present.

$Z = F + M$ is defined as the total instantaneous mortality coefficient. The differential equation has the form of a linear equation where the instantaneous total mortality rate (Z) is a constant of proportionality or the slope of the relationship between the rate of population loss and the population size.

The general form of the decay equation of population size is: $N_t = N_o e^{-Zt}$

This solution is known as the exploited cohort equation, the population decay equation, or the survival equation because it describes the decline in numbers over time, and provides the number surviving at any time t. The parameter N_0 is the number of animals in the population at time 0 and N_t is the number at time t. The parameter Z is the total instantaneous mortality rate which can be separated into natural (M) and fishing (F) mortality (*i.e.*, $Z = F + M$). The total instantaneous rate of mortality equals the sum of the instantaneous rates of natural and fishing mortality ($Z = F + M$).

If fishing mortality is equal to 0, then natural mortality is the sole cause of the cohort number decline. The natural mortality rate is directly related to the life span of the species. Long-lived species, with life spans of 15 or more years have relatively low natural mortality rates ($M \leq 0.2$). Short-lived species, with life spans of 5 years or less, have relatively high natural mortality rates ($M \geq 0.7$). Note that the life span of a species can be defined as the age of a cohort or years class when the population number is reduced to 5% of the stating number.

SECTION 6: FISHING GEAR SELECTIVITY

6.1 Background

Since the 1970's, considerable progress has been made in defining the selection characteristics of various fish harvesting gears. Fishery managers and fishing gear technologists have investigated the subtle characteristics of species-specific size selection as a function of mesh size and shape in trawls, mesh size and hanging ratio in gill nets, hook size and style in longlines, and mesh size and funnel opening size in traps, so as to provide improved management of fishery stocks harvested with these gear types.

The size selectivity of all fish harvesting gear can be classified broadly into two types of probability distributions:

1. A sigmoid curve, increasing from some positive value less than one to one as a function of fish size. This curve is represented by a logistic cumulative distribution function (LCDF). The selection characteristics of this curve are that all fish smaller than a particular size (L_1) are not captured (P = 0); that all fish larger than a particular size (L_2) are captured (P = 1); and that fish of a certain size (L_{50}) between L_1 and L_2 have a 50 percent probability of capture (P = 0.5) if encountering the gear.

2. A dome-shaped curve, increasing from some positive value less than one to one, then decreasing again as a function of fish size. This curve is represented by a truncated, rescaled normal probability density function (NPDF). The characteristics of this curve are that all fish smaller than a particular size (L_1) and larger than another particular size (L_2) are not captured, and that fish of a certain size (L_{opt}) between L_1 and L_2 have a 100 percent probability (P = 1.0) of capture if encountering the gear.

6.2 General Theory

Logistic Cumulative Distribution Function

The size selection characteristics of trawl cod-end meshes and some hooks can be represented by a logistic cumulative distribution function (LCDF) (Figure 5):

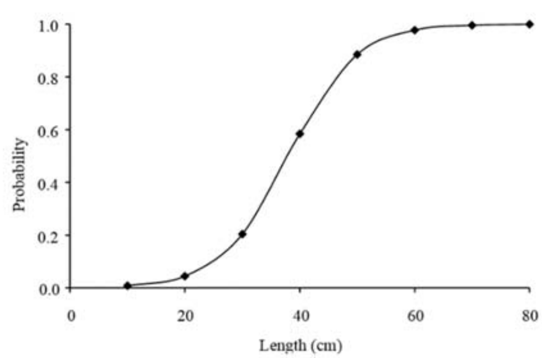

Figure 4: Probability of selection following a logistic cumulative distribution function.

6.3 Normal Probability Distribution Function

The size selection characteristics of gillnets and some traps are represented by a truncated, scaled normal probability distribution function (NPDF) (Figure 6):

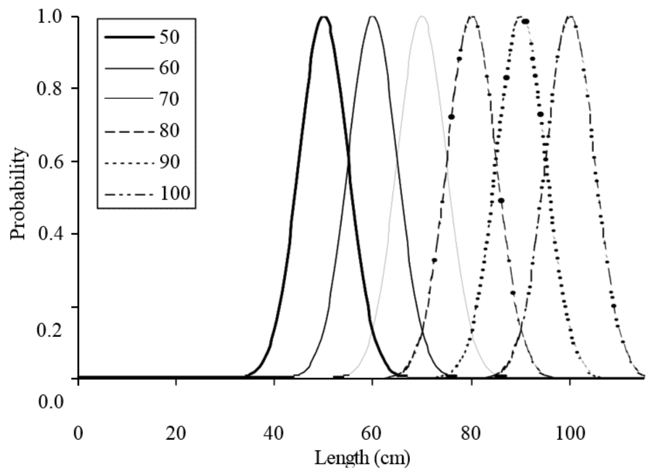

Figure 5: Probability of selection following a logistic cumulative distribution function.

SECTION 7: YIELD PER RECRUIT (YPR)

Yield-per-recruit (YPR) models are useful to fishery resource managers for predicting the effects of alterations in harvesting activity on the yield available from a given year-class or cohort. Two elements that define the model and are usually regulated by resource managers are fishing mortality (F) and the pattern of harvesting activity on different sizes of fish. Often the latter element has been simplified by assuming knife-edge selection (100% vulnerability at age of first capture). The Beverton and Holt analytical solution to the yield equation was initially developed to estimate YPR. While the knife-edge selection assumption may be appropriate for size selection that follows a logistic distribution function, as is observed in a trawl codend, the Beverton-Holt yield equation does not incorporate recent advances in understanding the size selection processes of the principal gear types used on groundfish (trawls, traps, gillnets, and longlines). To predict the yield from a given number of recruits in a single cohort of fish, parameters characterizing the life history of the fish species and affecting the harvest of the stock must be specified. While the life history parameters affect the potential biomass available from the cohort, harvest related factors are controlled by fisheries management and ultimately affect the yield taken from the biomass. The biological or life-history parameters affecting the potential maximum biomass and the timing of the maximization are:

K is the instantaneous growth rate,
M is the instantaneous natural mortality rate,
W_∞ is the maximum weight of an individual fish.

The fishery related factors affecting the maximum potential yield are:

- t_c is the age at which fish enter the fishery, controlled by mesh size in a trawl fishery,
- *F* is the instantaneous fishing mortality rate.

Beverton and Holt noted several important results from the yield per recruit analysis. Most important is the ratio of the growth parameter (*K*) to the natural mortality coefficient (*M*), which estimates the potential of a fish to complete its potential growth before dying of natural mortality.

If *M/K* is small (*M/K* < 0.5), then growth is high relative to mortality, and the cohort will reach maximum biomass at a larger size relative to the maximum size, or the stock (in the absence of fishing) will contain relatively larger fish. From a fishery perspective, management should maximize the size or age of entry to the fishery (t_c) with minimal fishing mortality on smaller fish.

If *M/K* is large (*M/K* >1.5), then natural mortality exceeds growth, indicating many fish will die before completing their potential growth. Again, from a fishery perspective, management should allow heavy fishing with a small size (early age) at first capture, so as to harvest the maximum biomass before they die of natural causes.

In general, the *M/K* ratio increases, the peak of the unfished cohort biomass curve (Figure 7) shifts to the left, suggesting that the age or length at which harvesting pressure should be applied is a smaller value.

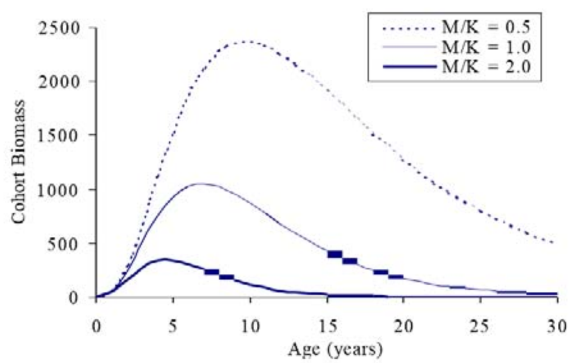

Figure 6: Effect of mortality rate on cohort biomass given a fixed growth rate.

The yield-per-recruit (YPR) analysis generates a function that describes the relationship between yield and fishing mortality for the specific biological parameters that describe the life history of the animal, and the fishery parameter that describes the age or size of entry into the fishery based on gear selectivity (Figure 23). At *F* = 0, there is obviously no yield, and as *F* increases, yield increases rapidly, reaching a maximum value (F_{MAX}), then either declines with increasing *F* or asymptotes, depending on the age or size of entry into the fishery. Harvesting at fishing mortality rates greater than F_{MAX} is not productive as it results in declining yield.

The corollary to the YPR analysis is the spawning stock biomass per recruit (SSBPR) analysis. In this case, the biomass of mature animals remaining in the cohort are determined after extracting the yield, and the animals are valued for their contribution to future recruitment for the stock. The SSBPR analysis generates a function that describes the relationship between spawning stock biomass and fishing mortality (Figure 8). At $F = 0$, the SSBPR value is at a maximum (unfished SSB), as there is no harvesting, and from there it declines sharply as F increases, finally approaching a minimum value at the highest F levels. The reference point $F_{20\%SSB}$ refers to the level of fishing mortality that retains 20% of the SSB at F=0.

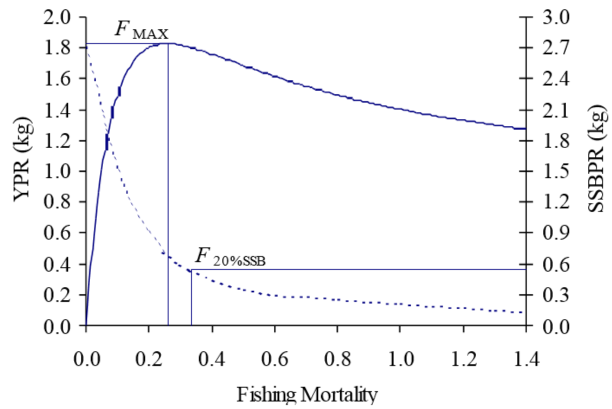

Figure 7: Yield per recruit (YPR) (–) and spawning stock biomass per recruit (SSBPR) (- - -) relationship.

SECTION 8: BIOMASS DYNAMIC MODELS (BDM)

The biomass dynamic models, also known as surplus production models, are among the simplest stock assessment models commonly employed by fisheries scientists to model population dynamics and track biomass. These models are designed to characterize the dynamics of a stock in terms of changes in total biomass without regard to age or size structure. They are generally used to derive estimates of historical abundance and mortality. A disadvantage of surplus production models is they cannot provide possible explanations for changes in abundance, because the changes in standing stock biomass, recruitment, and mortality are all examined collectively. The BDMs are used to assess stocks lacking information on age or size structure and also used as a secondary model to corroborate results from age- (or size-) structured models. They provide estimates of the biological reference points directly from the estimated population parameters while making assumptions that the stock is undifferentiated (e.g., no age, size, or gender differences), the catch is assumed to be large enough to signal a response in the population and catch rates are linearly related to stock abundance. This linear relationship implies the catchability of the species does not change over time. Another important factor affecting how well the BDM will fit available data is the contrast in the data over the time series. Contrast in the data means the CPUE or abundance index time series should have both declining and increasing periods of abundance. A simple "one-way" decline in an index or CPUE series is common to many fisheries data sets but does not provide information on a population's ability to increase during favorable conditions. An additional consideration for surplus production models is if the data display sufficient coverage (how well do the data encompass the high and low ranges of stock size?). Good coverage and contrast in the data are necessary to produce reasonable parameter estimates. The data needed to run the BDM is the total catch and effort (Total catch is assumed to be known without error). We can use an index of relative abundance of the stock (not just a portion of it) to calibrate the BDM fits. The BDMs do not require an estimated or assumed value of natural mortality in order to estimate exploitation rate. These models provide estimates of stock size (generally in biomass), exploitation rate, and biological reference points (MSY, B_{MSY} (the biomass resulting in MSY), and E_{MSY} (the effort resulting in MSY)). This model was used for the STWG stock assessments of small pelagic and demersal species. It is also used by FAO/CECAF for its assessment.

8.1 Model framework

A BDM model was fit to observed landings and fishing effort (*C,f*) data of small pelagics (sardinella, anchovies and mackerel) in Ghana. Fishing effort is represented by the number of canoes, calibrated to account for changes in gear efficiency. The model is a mass balance approach in which stock biomass ach year is the biomass the year before plus new production minus the catch removed. New production is the net difference between additions from growth and recruitment and mortality losses. The stock growth is assumed to follow the familiar logistic curve represented in this equation:

Equation 1

$$B_{t+1} = B_t + rB_t\left(1 - \frac{B_t}{K}\right) - C_t + \epsilon$$

Where:

t = year
B_{t+1} = population biomass of next year (t+1)
B_t = population biomass of this year (t)
r = intrinsic rate of increase in biomass
ϵ = lognormal process error

The (*r*) parameter is a measure of population growth rate at very low abundance when density dependent factors are inoperative. The term in parentheses is the density dependent feedback mechanism that reduces stock growth when abundance is high. The average catch rates (CPUE) is expressed as the product of biomass (*B*) and the catchability coefficient (proportion of the total stock taken by one unit of effort) represented by (*q*). The relationship between the catchability q and the CPUE is:

Equation 2

$$\overline{CPUE} = \frac{Catch}{Effort} = qB$$

Where:

q = catchability coefficient

$CPUE$ = Catch-Per-Unit of Effort

B = Biomass

The model is then fit iteratively by minimizing the sum of square residuals between observed CPUE and predicted CPUE in the form of:

Equation 3

$$\sum (CPUE - \overline{CPUE})^2$$

Where *CPUE,* representing an Index of abundance (I), is the observed rate from which to subtract the predicted or expected *CPUE* from the model.

The management quantities for sustainable fisheries can be derived from the logistic model parameters as follows:

Equation 4

$$MSY = \frac{rK}{4}$$

Equation 5

$$F_{msy} = \frac{r}{2}$$

$$B_{msy} = \frac{K}{2}$$

Maximum sustainable yield (MSY) is the maximum yield that a stock can deliver year after year over the long term. It is a function of both carrying capacity and stock productivity. In order to produce

MSY, a stock needs to be at a biomass level equal to one-half carrying capacity (B_{msy}) and be subject to a fishery removal rate no greater than F_{msy}. The latter is equal to one-half the maximum rate of stock growth. A fishing mortality rate that approaches the maximum rate of stock growth will lead to stock collapse (F_{coll}).

8.2 Fishing Effort Calibration

The abundance indices CPUE were calibrated based on fishermen's knowledge, using the information from the survey conducted by Hen Mpoano (Lazar et.al. 2016a) on historical trends of fishing capacity and gear efficiency. The CPUE were corrected using the results of the survey summarized in Table 1 as follows:

Equation 6

$$CPUE_{corrected(i)} = \frac{CPUE_{observed\ (i)}}{(1+\alpha)^{i-i_o}}$$

Where $CPUE_{observed(i)}$ is the raw number of canoes targeting small pelagics estimated by the frame surveys over the period from 1990-2016; $CPUE_{corrected(i)}$ is the corrected index for the period of years i, and α is the annual rate of increase of fishing power of the artisanal canoe fishery.

The increase in efficiency is linked to modernization of the canoes, increased horsepower of outboard engines, and increase in net size. The use of light fishing is another factor improving efficiency, however the FSSD report of 2005 demonstrated no evidence of the use of light fishing. (Bannerman, 2005). Fishermen believe that light fishing is a significant tool for increased fishing efficiency and success. A study to better measure claims of increased efficiency resulting from light fishing could be useful and might result in a revised calibration to improve the fit of the surplus model (Lazar et. al. 2017).

SECTION 9: STOCK AND RECRUITMENT

The stock-recruitment (S/R) relationship is fundamental to the management of natural resources, especially fish and shellfish stocks. The nature of this relationship is used to determine to what extent a population may be harvested by either commercial or sport fisheries. The S/R relationship is normally presented graphically as a scatter plot with the number of females in the spawning stock on the x-axis and the number of recruits on the y-axis (Figure 9). The spawning stock is defined as the number of female organisms in the population of reproductive age and able to reproduce in any one year. The recruits are defined as those young who survive to either maturity, or to be captured by the fishery.

The replacement line is where stock = recruits. Any recruits above this line are considered to be "in excess" of that required to maintain the population, and can therefore be harvested without impact to the population.

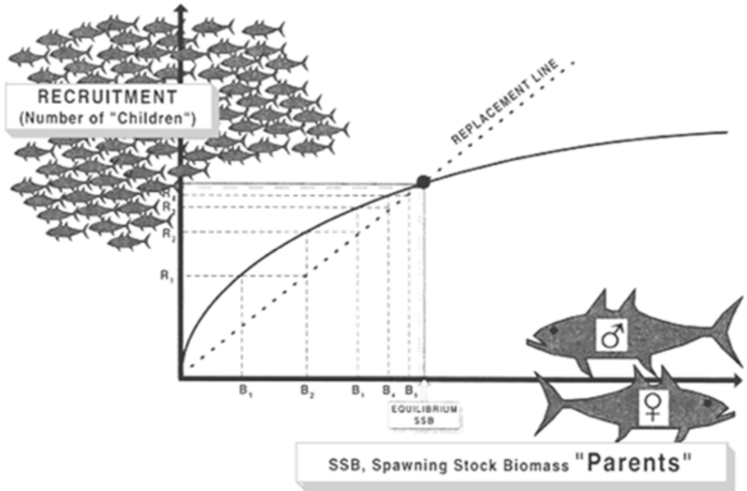

Figure 9: The effect of the value of the growth coefficient (K) on the growth curve.

There are two classical mathematical models used to describe the relationship between spawning stock biomass and recruitment. The first is called Beverton-Holt model described by the following equation:

$$R = SS / (SS + g*R_{max})*R_{max}$$

Where R is the number of recruits, SS is the spawning stock expressed in number of eggs or number of mature females and g is an equation parameter.

Ricker and Schnute have proposed a variant of the above model which accounts for density dependence compensation effects. However, these models do not account for environmental effects of recruitment.

SECTION 10: GROUP EXERCISE

The participants were divided into three groups and were provided with a simulated catch effort data for a collapsed fisheries case. A data time series of 15 years with missing information in 3 consecutive years on catch and effort of the artisanal small pelagic fishery in Ghana. Participants were tasked with finding appropriate statistical methods to fill in the missing data and justify their assumptions. Then they worked on data analysis and fit the appropriate stock assessment model and provide a status of the stock by estimating the current biomass and fishing mortality and displaying the trends of these two parameters over the 15 year-period. The results also included estimates uncertainty of model run (%CV) and presented the results in easy to read graphics.

The groups were asked to summarize the results and present a succinct summary to the “Minister of Fisheries” in a five-minute presentation because of the busy schedule of the “Minister”. Each group proposed some fisheries management recommendations on the basis of these results. In addition, each group was asked to make research recommendations on how to improve future fisheries data and stock assessment.

The three groups found that the stock is overfished to severely overfished and that fishing mortality exceeded the sustainable level by as much as 80% while biomass reached the lowest level in the last year of the fifteen-year period. The recommendations called for:

- Total ban on fishing until fish stock recovers.
- Government must seek funding from parliament to support loss of jobs and livelihood until the stock recovers.
- Minister must work with the fishing industry to raise awareness to declare fisheries situation as a disaster so to allow relief programs from parliament.

- Stop issuing new licenses to foreign vessels and declare moratorium on new entrants in the artisanal fisheries.
- Revise the laws to stop joint-ventures businesses with Chinese.
- Improve fisheries data collection and hire more field enumerators.

Figure 10: The Minister and her Deputy' during the mock presentation

Figure 11: A participant delivering during the mock presentation