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# Review on fish stock assessments models with more emphasis on the use of empirical and analytical models for potential yield prediction

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**Abstract**
The basic purpose of fish stock assessment is to provide estimates of the state of the stock to assure, in the long run, the self-sustainability of the stock under exploitation. The three commonly used stock assessment models are reviewed in this paper namely Surplus production model, Empirical model, and Analytical Model. The first model is simpler and considers the stock as a homogenous biomass. It ignores the complexities of age structure and spatial structure and assumes compensatory population growth and provides fishery managers with some important management parameters. Nonetheless, it requires a long time series catch and effort data and assumes stock has stabilized at a current rate of fishing and its ability to accurately describe and predict the dynamics of fish populations depends greatly on the nature of the available data. The second model makes a link between some easily measured characteristic of a water body, such as its area/depth, the conductivity of the water or the mean primary production and an expected yield. However, a major limitation of the Empirical model is that previously observed empirical relationships may break down in situations when conditions change substantially. The third model, on the other hand, requires a detailed description of the stock such as size or age structure of the stock as well as growth and mortality parameters that characterize the population under investigation. As an advantage, this model gives a reliable estimation of yield and biomass of fish that could be exploited sustainably from a given water body. However, such model has been poorly used in developing countries. Since, it is complex, slow, costly and time-consuming. In conclusion, understating the limitation, advantages and applications of each stock assessment model is very important to make a reliable estimate of vigorous fisheries management parameters in order to manage our aquatic resources sustainably.

**Keywords:** Analytical, comparison, empirical, fish stock assessment, surplus production, model

## Introduction

Fisheries are renewable resources which means replenish by natural processes at a faster rate than its rate of loss and fishing should not offset this natural balance. At very high levels of exploitation, the removal will best a stock's regenerative capacity eventually leading to a collapse of the fishery. Thus the point somewhere between no effort and very high effort needs to be found that will give the maximum average yield with a maximum regenerative capacity of the stock (King and Ludke, 1995) [9].

A stock of fish or a unit stock can be defined as a subset of a species, which is generally considered as the basic taxonomic unit having the same growth and mortality parameters and inhabiting a particular geographical area (King and Ludke, 1995; Sparre and Venema, 1998) [9, 20]. Stock assessment is the part of Fisheries Science that studies the status of a fish stock as well as the possible outcomes of different management alternatives. It is used to understand if the abundance of a stock is below or above a given target point and thus, whether the stock is overexploited or not; stock assessment can also indicate if a catch level will maintain or change the abundance of the considered stock (Musick and Bonfil, 2004) [14]. Fisheries science has naturally developed into using mathematical and statistical descriptions of the processes in attempts to understand the dynamics of exploited populations that is to explain biological processes using mathematical models. Models are a simplified mathematical description of processes happening in a water body. And they are the processes linking input and output usually in the form of mathematical expression comprising variables, parameters, and operators (Sparre and Venema, 1998) [20].

A wide variety of model types have been applied to issues of fishery resource management (Metcalfe *et al.*, 2012) [12].

There are three basic groups of models in fish stock assessment namely the Holistic, Empirical and Analytical models each having specific requirements in terms of data and ability to perform calculations. Each model has also its own assumptions. Evaluating whether the assumptions are reasonably met is a very important part of every stock assessment work.

Holistic Models are generally simpler and consider the stock as a homogenous biomass disregarding the details required by analytical models (Fox and William, 1970) [4].

Empirical models make a link between some easily measured characteristic of a water body, such as its area, the conductivity of the water or the mean primary production and an expected yield. Basically, when an empirical model is applied, a given water body is being compared with the original group which means the water body which is going to studied should not be too different from the ones in the original data base. If not, the emperical model is not applicable (Reyntjens and Tesfaye Wudneh, 1998) [17].

Analytical models, on the other hand, require a more detailed description of the stock or Age structure of the stock as well as growth and mortality parameters that characterize the population under investigation. As compensation, these models give a reliable estimation of yield and biomass of fish that can be exploited sustainably from a given water body (Ricker, 1975) [18]. The most desirable feature of analytical models is that they are used to predict future yield and biomass at different levels of fishing effort. Thus these models can be used to forecast the effect of the future development of fishery industry on the population such as the effect of increase or decreases of fishing efforts, changes in fishing gears or mesh size etc. on the yield and biomass of the fish. These models, therefore, make a direct link between fish stock assessment and fishery resource management. Accordingly, the final aim of the use predictive models is to provide those responsible for management of the fishery with information on the biological and economic effect of fishing on the stock (Beverton and Holt, 1957; Pauly, 1983; Hilborn and Walters, 1992) [1, 15, 7].

There are two types of analytical models namely Beverton and Holt yield per recruit model (Beverton and Holt, 1957) [1] and Thompson and Bell model (Thompson *et al.*, 1934) [21]. The former model takes input variables derived from samples taken from the commercial fishery whereas the latter model requires input data derived from a total census of the catch and knowledge of the total population size by age group. The latter model, although more demanding in terms of data requirement, it gives more reliable predictions than Beaverton and Holt model.

The main objective of this paper is to review the application, advantages, and limitation of the three models in fish stock assessment with particular emphasis on tropical fish assessment. In due regards, the first section of the paper covers the application of Surplus production models, in the second section the application of Empirical models, in the third section Analytical models (Beaverton and Holt yield per Model and Thompson and Bell yield predictive model) and Finally observed discrepancies in the empirical and analytical models would be discussed.

**Use of Surplus Production Model for potential yield estimates**

The SPM is one of the simplest analytical methods that can be used to assess fish stock. Its simplicity arises from the fact that it is parsimonious (many parameters of the model are pooled) and that it requires only a minimum amount of data. Actually, SPM needs only a series of catches and abundance index (Lemay, 2007) [10]. The SPM models only the stock dynamics and does not take into account the age structure of the stock population, as some other models, such as VPA, do (Lemay, 2007) [10]. The objective of the application of "surplus production models" is to determine the optimum level of effort that is the effort that produces the maximum yield that can be sustained without affecting the long-term productivity of the stock, the so-called maximum sustainable yield (Sparre and Venema, 1998) [20].

The SPM is used to study how a fish population is responding to harvesting. Because SPMs are often used with few years of observations (usually 20 to 30), a good estimation is hard to obtain if catch data are too stable (Lemay, 2007) [10]. This means that a good dataset should indicate various catch intensities relative to the stock population size (which is unfortunately unknown before the analysis). Such a variability helps the model in its evaluation of the stock response to high and low catch levels (is the population able to recover rapidly or slowly?). For example, if a population is very large and harvesting is very low relative to stock size during all the periods of interest, there will not be enough contrast in the perturbations made to the population to estimate the SPM parameters (Lemay, 2007) [10].

Graham and Schaefer were two of the important British scientists who proposed the logistic equation for population growth

$$\frac{dB}{dt} = \frac{r * Bt\,(B\infty - Bt)}{B\infty - Ct} \quad \text{or} \quad \frac{dB}{dt} = r * Bt\,\frac{(1-Bt)}{B\infty} - Ct \;\ldots\ldots\ldots\ldots\ldots 1$$

Where, $r * Bt\,\frac{(1-Bt)}{B\infty}$ is the natural biomass increase, also called surplus production; r =intrinsic rate of population increase; B =Population biomass; Boo= virgin biomass of Population; t= time, r= intrinsic rate of increase (rate of natural increase) which means the difference of recruit rate for fish and mortality.

The net production (also called “surplus production”) of a population is highest at $B\infty/2$. Consequently, a fishery that maintains its resource at $B\infty/2$ would harvest the highest surplus production of the resource. Under equilibrium conditions, the surplus production/time of the stock is a parabolic function of the fishing effort (f) and the population size (Boo); and the catch per unit effort (C/f) is linearly related to the fishing effort (Sparre and Venema, 1998) [20].

The distinction between Schaefer and Fox Model is Schaefer assumed that at a given high level of effort the yield tends to become zero as the stock gets totally exhausted. While the later assumed that the stock cannot totally exhaust to extinction at extreme effort levels and hence the yield does not become zero. Instead, the yield approaches the x-axis asymptotically (Garcia *et al.*, 1989) [5]. However, there is no major difference between the two models regarding the outputs obtained (Sparre and Venema, 1998) [20].

**Advantages and Limitation of Surplus production Model**

A surplus production model is a fishery model of simplified population dynamics. It ignores the complexities of age structure and spatial structure. One attractive feature of the model is that it can provide fishery managers with some important management parameters: the maximum sustainable yield, the biomass ($B_{MSY}$) producing MSY, the level of fishing rate ($F_{MSY}$) or effort ($E_{MSY}$) that drives the population to the biomass level producing MSY, and the maximum exploitation rate (Emax) that the population can sustain (Zhao and Lester, 2013) [23]. In addition, it predicts the trajectory of population growth, the status of the current population, and its surplus levels. Compared to other fisheries models, surplus production models need relatively little data to estimate population parameters: only total harvest and effort data are required to estimate historical biomasses (Garcia *et al.*, 1989) [5].

Nonetheless, it assumes stock has stabilized at a current rate of fishing and its ability to accurately describe and predict the dynamics of fish populations depends greatly on the nature of the available data. This type of model is often used when catch-at-age information is not available to develop a more sophisticated age-structured model (Zhao and Lester, 2013) [23]. Furthermore, it does not incorporate environmental factors and mechanisms affecting the population dynamics and also it excludes trophic linkages among the organism (Zhao and Lester, 2013) [23].

**Empirical Models**

**Use of empirical models for potential yield estimates**

Simple empirical estimators have been used to predict fish yields in lakes and reservoirs for over 30 years (Ryder and Henderson, 1975; Mekonen Sefi, 2016) [19, 11]. The theoretical basis for such models is that fish production is largely determined by the level of primary production in an aquatic system. As production rates are difficult to measure, factors thought likely to affect primary production, such as the depth of a lake and some measure of its nutrient status (such as conductivity) have been correlated with fish yield (a function of fish production) obtained from fishery data.

Numerous predictive models, based on a variety of physicochemical and biological parameters, have been developed to provide a general indication of potential fish yields from lakes and reservoirs in different regions (Janjua *et al.*, 2008) [8]. Although all these models have some limitations in their application, in the absence of actual production data, they can provide a preliminary estimate of potential fish production. The production of fish in lakes, rivers, and reservoirs is affected by a complex, interacting set of factors, including age and morphometry of the water body, physical parameters, water chemistry and biological structures and function (Janjua *et al.*, 2008) [8].

Morpho-edaphic index (MEI) is well-known empirical predictor and it has been used, often in conjunction with other explanatory variables such as lake surface area and temperature, for prediction of fish yields per unit area in lakes and reservoirs around the world (MRAG Ltd, 1995) [13]: The MEI was originally developed by Ryder (1965) for temperate lakes to predict fish yield.

The first application of Ryder's morpho-edaphic index to tropical fisheries was that of Henderson and Welcomme (1974):

$$Y = 14.3136\ MEI^{0.4681}\ (r = 0.6864) \qquad 2$$

This relationship was derived from 17 of an original dataset of 31 African lakes. The reduced data set includes only those lakes considered to be fully exploited (>1 fisherman $km^{-2}$ lake area). The regression line has a similar slope but higher intercept than the original MEI proposed by Ryder (1965) for a series of North American lakes and Toews and Griffith (1979) modified their model by including lake surface area in the relationship and it becomes:

$$\log_{10}Y = 1.4071 + 0.3697 \log_{10}MEI - 0.00005465\ A;\ r = 0.81 \qquad 3$$

Where Y = potential sustainable fish yield in kg $ha^{-1}$ $yr^{-1}$, MEI = morpho-edaphic index = conductivity (µmho $cm^{-1}$at 20º C)/mean depth in meters and A = lake surface area ($km^2$)

Schlesinger & Regier (1982) recognized that fish yield - MEI relationships generally applied only to lakes within restricted regions and attempted to generalize the relationship by incorporating mean annual air temperature (T; ºC) to account for latitudinal variations;

$$\log_{10}Y = 0.044\ T + 0.482 \log_{10}MEI + 0.236;\ n = 43,\ r = 0.90 \qquad 4$$

The disadvantage of the MEI is that it only applies to lakes which are relatively homogenous with regard to their chemical composition and geographical location so that a different MEI relationship should be derived for each region (MRAG Ltd, 1995) [13].

A more recent analysis has established a relationship between fish production ($P_f$) and TP (Downing *et al.*, 1990) [3].

$$\log_{10}P_f = 0.332 + 0.531\log_{10}TP;\ n = 14,\ r = 0.82 \qquad 5$$

The use of fish production, rather than yield, removes the variability due to differences in exploitation rates and variability in the relationship between fish production and yield but is less useful in fisheries management terms as fish production is not normally known, whereas yield data are commonly available (MRAG Ltd, 1995) [13].

Recent models have tended to the trivial conclusion that lake area explains most of the variance in fish landings (bigger lakes yield more fish!). Cruel derived the following relationship between catch ($ty^{-1}$) and area ($km^2$) for 46 lakes and 25 reservoirs in Africa (Crul, 1992) [2]

$$Catch = 8.32 * Area0.92\ r^2 = 0.93 \qquad 6$$

This relationship explained a high proportion of the variance because the range of areas and catches was large. Predictions for individual water bodies from this relationship are very imprecise, and no relationship incorporating other morphometric, chemical or biological parameters could be derived (MRAG Ltd, 1995) [13]. Quiros derived a number of yield: area relationships of the same general form for Latin American water bodies (MRAG Ltd, 1995) [13]. Several other empirical relationships have been derived from some easily measured characteristic of a water body and fish production (yield).

The research was conducted in Shahpur Dam, Pakistan, to compare different empirical predictive models for estimating fish yield with the actual yield. Physiochemical and fisheries studies were conducted from July 2001 to June 2002 on a monthly basis. Hydrographical data for the reservoir for the years 2001–2002 were obtained from the Small Dam Organization, Punjab. Metrological data were obtained from the nearby research station of the Water Resources Research Institute (NARC). Three sites were selected for measuring physiochemical parameters and collection of water samples for analysis. Mean values from these sites were taken for the compilation of the monthly data. Temperature, TDS, and conductivity were measured in the field, using various microprocessor meters (Janjua *et al.*, 2008) [8]. Water samples were collected in plastic bottles, with the alkalinity being measured in the laboratory via titration. Morpho-edaphic indices were calculated on a monthly basis. Fish catch data were collected from commercial catches every week. The number of boats and total fishing days was recorded, in order to calculate the total boat days and the fishing intensity. The total catch per month was calculated by multiplying the mean fish catch per day by the number of days in that month. The fish yield per hectare was calculated by dividing the total fish catch during the fishing season by the mean pond area during the year (Janjua *et al.*, 2008) [8].

The seven empirical fish yield predictive models based on different parameters were compared to the calculated fish yield from fish catches and presented as follows.

**Table 1:** Fisheries Statistics for Shahpur Dam, 2001–2002 (Fishing intensity was almost constant throughout the fishing season, with only occasional changes in the number of boats and nets). (Janjua *et al.*, 2008) [8]

| Numbers of nets | Numbers of pound nets | Numbers of boats | Numbers of fishing days | Numbers of boat days | Fishing intensity (boats $day^{-1}ha^{-1}year^{-1}$) | Catch per unit effort (kg $boat^{-1}day^{-1}$) | Fish yield from catches (kg $ha^{-1}year^{-1}$) |
|---|---|---|---|---|---|---|---|
| 150 | 8 | 10 | 273 | 2730 | 9.63 | 10.57 | 101.92 |

**Table 2:** Different empirical models and estimated predictive fish yields (Y) for Shahpur Dam. Modified from (Janjua *et al.*, 2008) [8]

| Model Number | Derived relationship | Predicted yield($Kg^{-1}ha^{-1}year^{-1}$) | Model developed by: |
|---|---|---|---|
| 1 | $Y = 14.3136\ MEIc^{0.468}$ | 91.88 | Henderson and Welcomme (1974) |
| 2 | $\log Y = 1.4071 + 0.3697 \log MEIc - 0.00005465\ A$ | 110.6 | Toews and Griffith (1979) |
| 3 | $\log Y = 0.044\ T + 0.428 \log MEIt + 0.236$ | 104.7 | Schlesinger and Regier (1982) |
| 4 | $Y = -3.3 + 3.2\ FI + 2.86\ MEIa$ | 115.8 | Nissanka *et al.* (2000) |
| | $Y = 50.3 - 1.7\ FI + 1.28\ MEIc$ | 101.8 | |
| 5 | $Y = -30.3 + 13.6\ FI + 1.76\ Chl\text{-}a$ | 136.1 | |
| | $Y = -47.1 + 15.8\ FI + 1.81 CA/RA$ | 235.2 | |
| 6 | $Y = 20.5 + 6.61 FI + 0.00722 CA/RC$ | 168.1 | |
| 7 | Estimated from 2001-2002 fish catches | 101.92 | |

(Model 4 predicts a yield close to the estimated fish yield based on fish catches; mean values for 2001–2002 (Table 2) were used to calculate the relationships)

Different empirical models estimated dissimilar predictive fish yields (Y) for Shahpur Dam (Table 3). Model 4 predicts a yield close to the estimated fish yield based on fish catches; mean values for 2001–2002 (Table 2) while models 5–6 show a high level of prediction. According to the researchers, the variation among predictive models may be due to fish yield–MEI relationships are applicable only to lakes within specific regions, Thus developing regional-specific predictive model is important (Janjua *et al.*, 2008) [8].

### Advantages and Drawbacks of Empirical approach

Empirical models offer the potential for obtaining an inexpensive parameter estimate from an easily measured surrogate when the parameter is difficult and costly to measure directly (Mekonen Sefi, 2016) [11]. It has been widely used in Asian and African lakes, reservoirs and rivers where fisheries data are not readily available since they are simple, quick and cost-effective. However, these estimates should be considered with great caution (Gashaw Tesfaye and Wolff, 2014) [6] and the compelling mean of several predictions (based on different models) would appear most useful in providing realistic estimates.

Empirical models describe processes with empirical or statistical relationships that are developed based on observations (Ready *et al.*, 2010) [16] and often represent complex processes in simple equations with relatively few parameters. However, a major limitation is that previously observed empirical relationships may break down in situations when conditions change substantially. Empirical models, therefore, offer only limited power for extrapolation (Vander, 2006) [22].

Although empirical models do not explicitly represent the fundamental processes driving the dynamics of a system, the empirical relationships used within a model supposedly capture the net or emergent effects of the underlying processes.

Empirical models have several severe drawbacks such as:

- The water body studied should not to be too different from the ones in the original database. If not, the empirical model is not applicable;
- They do not give any insight into what is actually happening in the fishery or with the stocks;
- The estimates of the potential production have very wide confidence limits;
- They do not estimate optimal or safe levels of fishing effort and it is impossible to evaluate the impact of changes in fishing effort

### Analytical Models

#### The use of Analytical models for potential yield estimation

Analytical models estimate fish yield from catch and effort data, which is structured by length and/or age group. And these models require a more detail description of growth and mortality parameters that characterize the population. As compensation, these models give a reliable estimation of yield and biomass of fish that can be exploited sustainably from a given water body (Ricker, 1975) [18].

There are two types of analytical models namely Beverton and Holt Yield per recruit model (Beverton and Holt, 1957) [1]. And the Thompson and Bell Model (Thompson *et al.*, 1934) [21]. The former model takes input variables derived from samples taken from the commercial fishery whereas the latter model requires input data derived from a total census of catch and knowledge of the total population size by age group. The latter model, although more demanding in terms of data requirement, it gives more reliable predictions than Beaverton and Holt model. As a result, it is more favored in regions where the census of the total commercial landing is taken in combination with rigorous age determination work (Shepherd, 1988). Data availability is the major constraint to use these models for tropical fish stock assessment, in particular concerning the Thompson and Bell Method.

**Beverton and Holt yield per recruit model**

The Beaverton and Holt model is a method estimating fish yield on a per recruitment basis, i.e., yield that can be obtained from a given cohort after the fish attained the age of the first capture and until they die out at a certain old age (Beverton and Holt, 1957) [1]. The model is designed based on the experimental decay model that describes the life history of a cohort of fish. Accordingly, fish are recruited to the fishing grounds at a certain age, which is the age of first recruitment to the fishery (Tr) but they are not readily captured by the gears until they attain the age of first capture (Tc). As a result of the age of recruitment and age of the first capture, their numbers reduce because of natural mortality (Sparre and Venema, 1998) [20].

The following input parameters are required for Beaverton and Holt yield per recruit model:

Z, M, F, W∞, k, too, etc, tr

The simplification of the original formula is presented as follows:

$$\frac{Y}{R} = F * e^{[-M*(tc-tr)]} * W\infty * \{\frac{1}{[F+M]} - \frac{3S}{[F+(M+K)]} + \frac{3S^2}{[F+(M+2K)]} - \frac{S^3}{[F+(M+3K)}$$

............................7

Where,

$S = e^{-K*(TC-to)}$

K = Von Bertalanffy growth rate constant

to = Theoretical age of fish at zero length

W∞ = Asymptotic body weight

TC = Age at first capture

tr = Age at recruitment

F = Coefficient of fishing mortality rate

M = Coefficient of natural mortality rate

The relationship between yield (Y) and mean biomass (B) of fish in the water is expressed as follows (Venema *et al.*, 1988).

Y=F*B...................................................................................8

From this, the mean biomass per recruit can be calculated as;

$$\frac{B}{R} = \frac{1}{F} * \frac{Y}{R}$$

...................................................................................9

Then inserting equation 16 into equation 18, the expression for mean biomass per recruit can be written as follow.

$$e^{[-M*(tc-tr)]} * W\infty * \{\frac{1}{[F+M]} - \frac{3S}{[F+(M+K)]} + \frac{3S^2}{[F+(M+2K)]} - \frac{S^3}{[F+(M+3K)]}$$

.............................................10

Note that equation 9 is simply obtained by omitting F in the first term (right-hand side) of equation 6.

The application of yield per recruit and biomass per recruit models (equation 6 and 9) is illustrated using *Clarias gariepinus* Lake Hawassa (T-Giorgis and Tesfaye unpublished data).

**Prediction of Yield and Biomass per recruit for *C. gariepinus* in Lake Hawassa**

Estimates of growth and mortality parameters for *C.gariepinus* stocks of Lake Hawassa is used as input for running the yield per recruit model of Beaverton and Holt. The growth parameters were obtained from previously conducted age assessment work and mortality parameters were derived from catch curve analysis conducted based on sample catch statistics data collected from commercial fishery of Lake Hawassa (T-Giorgis and Tesfaye unpublished data). And the data are presented as follows;

**Table 3:** Growth and mortality parameters for *C.gariepinus* in Lake Hawassa used as input data for the Beaverton and Holt yield per recruit model

| **Lake Hawassa *C.gariepinus*** | |
|---|---|
| **Parameters** | **Values** |
| L∞ | 121 cm |
| W∞ | 14475 |
| K | $0.16\ yr^{-1}$ |
| To | -0.68 yr |
| Tr | 1 yr |
| Tc | 2 yrs |
| M | $0.33\ yr^{-1}$ |
| F | $0.97\ yr^{-1}$ |
| Z | $1.30\ yr^{-1}$ |
| **Calculated values for terms independent of F in equation 15 and 18** | |
| $e^{[-M*(tc-tr)]} * W\infty$ | 10406 |
| S | 0.6513 |
| 3S | 1.9539 |
| $3S^2$ | 1.2726 |

| | |
|---|---|
| $S^3$ | 0.2763 |
| M+k | 0.49 |
| M+2k | 0.65 |
| M+3k | 0.81 |

Note that the lower part of the table also shows results of preliminary calculations for the term independent of F

Thus the above expressions were employed to predict yield and stock biomass using different values of fishing mortality coefficients. For example, the value of fishing mortality corresponding to the current level of fishing effort applied in Lake Hawassa (0.97 $yr^{-1}$) gives predicted values of Y/R=618 per recruit.

**Table 4:** Predicted values of Yield and biomass per recruit for F values ranging from 0 to 2 $yr^{-1}$ for the stock of *C.gariepinus* in Lake Hawassa

| **Lake Hawassa** *C.gariepinus* stock | | |
|---|---|---|
| **F($yr^{-1}$)** | Y/R(g) | B/R(g) |
| 0 | 0 | 6863 |
| 0.05 | 265 | 5307 |
| 0.1 | 424 | 4236 |
| 0.2 | 580 | 2900 |
| 0.3 | 639 | 2130 |
| 0.4 | 658 | 1645 |
| 0.5 | 660 | 1320 |
| 0.6 | 654 | 1091 |
| 0.7 | 646 | 922 |
| 0.8 | 636 | 794 |
| 0.9 | 625 | 695 |
| 1 | 616 | 616 |
| 1.1 | 606 | 551 |
| 1.2 | 598 | 498 |
| 1.3 | 590 | 454 |
| 1.4 | 582 | 416 |
| 1.5 | 576 | 384 |

The value of Y/R is maximum (i.e., 660g/recruit) at a level of fishing mortality F=0.5 **$yr^{-1}$**(Table 5). This value of Y/R is called the maximum sustainable yield per recruit (MSY/R) and the corresponding value of F is the biologically optimum fishing mortality ($F_{MSY}$).
These results indicate that the current level of fishing mortality in Lake Hawassa is twice higher than the biologically optimum level estimated from the analysis (0.5 $yr^{-1}$)(Table 5). Thus the fishing effort in Lake Hawassa needs to be reduced sustainably to maintain a sustainable level of exploitation.

**Assumptions of Yield per recruit Model**

This model is in principle a steady state model and it describes the state of the stock and the yield in a situation when the fishing pattern has been the same for such a long time that all fish alive have been exposed to it since they were recruited (Beverton and Holt, 1957) [1]. In addition to this, the following assumption needs to be fulfilled for the model to function properly.

a. Recruitment is constant from time to time so that the same number of fish is recruited to the fishery year after year.
b. All fish of the cohort are hatched at the same time.
c. Recruitment and selection are ‘Knife edge’ which means that at age Tr all fish belonging to a given cohort recruit to the fishing ground and that at the age of first capture all of them are assumed to be exposed to full fishing mortality
d. The fishing and natural mortalities are assumed to remain constant from the moment of entry to exploitable phase.
e. There is a complete mixing of the stock.

In general, the Beaverton and Holt method works well under steady state and constant parameters system. On the other, the Thompson and Bell model is generally more flexible and it is entertained in the following sections.

**Thompson and Bell yield prediction model**

Thompson and Bell yield model enables prediction of yield on an absolute basis, unlike the Beaverton and Holt model that gives yield estimates on a per recruitment basis. The Thompson and Bell yield model is the first yield prediction model developed in the thirties (Thompson *et al.*, 1934) [21] but because of the extensive calculation involved, it did not gain popularity until the introduction of computers. Nowadays, this model is used as a standard method of yield prediction, in particular in regions where VPA and cohort analyses are conducted. This model has age-based and length based versions, in which the former is more applicable to temperate regions where age determination work is relatively easier than in the tropics. On the other hand, the length based version is more favored for tropical fish stock assessment work.
Thompson and Bell yield model comprises two main stages, provision of inputs and calculation of outputs in the form of predictions of yield and stock biomass for different levels of fishing mortalities. The input data for this method consists of the following (Sparre and Venema, 1998) [20]

1. Total number of fish caught per year structured by length group
2. Estimates of fishing mortalities
3. Estimates of population sizes(N) per length group
4. The mean weight of fish for each length group

5. Values of Von-Bertalanffy growth parameters ($L\infty$ and k) and estimates of the average natural mortality coefficient (M).

Then the main outputs from the input data comprise the yield (catch in weight) and mean stock biomass by length group. The yield in weight was calculated by multiplying the annual catch in number by mean weight of each length group.

$$Y (L_i, L_{i+1}) = C (L_i, L_{i+1}) * W (L_i, L_{i+1}) \text{............................} 11$$

Where,
$Y (L_i, L_{i+1})$ = the yield (weight) of fish obtained per year from respective length group
$C (L_i, L_{i+1})$ = total annual catch of fish obtained from respective length group
$W (L_i, L_{i+1})$ = the mean weight of each length group estimated using length-weight relationship
And

$$B (Li, Li+1) = Y (L_i, L_{i+1})/F (L_i, L_{i+1}) \text{.............................} 12$$

Where,
F=fishing mortality coefficient and others are as mentioned in equation 20
After calculating the yield and stock biomass per length group, the annual total yield and biomass of the stock were calculated by adding the contribution of each length group.

**Advantages and Limitations of Analytical predictive model**
The most desirable features of analytical models are that they are used to predict future yield and biomass at different levels of fishing effort. Thus these models can be used to forecast the effect of the future development of fishery industry on the fish population such as the effect of increase or decreases of fishing effort, changes in fishing gears or mesh size etc. on the yield and biomass of the fish. These models, therefore, make a direct link between fish stock assessment and fishery management as well as it provides information on the biological and economic effects of fishing on the stock (Pauly, 1984).
However, the majority of global fish stocks lack adequate data for estimating sustainable fishing levels using analytical stock assessment methods. In developing countries, only 5–20% of fish stocks are assessed using ‘data rich’ assessment methods mainly because of costs and time-related with data collection and analysis (Costello *et al.*, 2012).
In addition, the method don’t not incorporate the major limnological and environmental factors which may have a direct effect on the fish productivity of a given water bodies and models underestimate fishing mortality coefficient, in the areas where the predatory birds (Cormorants) are dominant. Considering their impact on fishery is important. This part would be more illustrated in the next section in more detail.

**Summary**
The first question which is usually asked to a fisheries scientist is: How much can we catch without endangering the resource? There are several tools, called models, which can be used. Models are simplified mathematical description of processes happening in a water body. There are three basic groups of models each having specific requirements in terms of data and ability to perform calculations. Each model has also its own merits and demerits as discussed in this paper.
Surplus production models need data on average catch per unit effort for several years. Also, fishing effort needs to have undergone substantial changes over the years covered. These models are based on theories describing how much a stock will produce at different levels of biomass but they do not take into account factors such as growth or recruitment. The amount produced would then correspond to the "surplus" which can be removed safely to bring back the stock to its original status. The application of these models consists fitting a mathematical model to data by a procedure known as regression analysis. The two well-known surplus production models are Schaefer and Fox model. However, there is no significant difference between the two approaches as discussed in section 1.
Empirical models make a link between some easily measured characteristics of a water body, such as its area, the conductivity of the water or mean primary production and expected yield. This link needs first to have been established empirically for a group of water bodies for which both yield and the considered characteristic are known. Basically, when an empirical model is applied, a given water body is compared with the original group. Empirical models also relate natural mortality to growth, reproductive effort, and environmental variables and are widely used as an inexpensive source of natural mortality estimates in developing countries (Venema *et al.*, 1988) where funds are limited for direct estimation techniques (e.g. age-structure analysis, tagging).
However, Empirical models have several drawbacks. The water body studied should not be too different from the ones in the original database. If not, the empirical model is not applicable. They do not give any insight into what is actually happening in the fishery or with the stocks. The estimates of the potential productions are not much better than educated guesses.
The third important mathematical model in fish stock assessment is analytical model which requires a detailed description of the stock such as size or age structure of the stock as well as growth and mortality parameters that characterize the population under investigation. As a result, such models provide reliable estimation of yield and biomass of the stock that can be exploited sustainably from a given water body.
There are two types of analytical models namely Beverton and Holt yield per recruit model and the Thompson and Bell model as discussed in section 3.The Input data for Beverton and Holt method come from analysis made on sample catch rather than from total census of the catch. Whereas the Thompson and Bell model requires the input information derived from total census of the landings and it is more flexible and works under restricted conditions than Beverton and Holt model. Apart from this, the other desirable feature of the Thompson and Bell model is the fact that it allows analysis of the bio-economic aspects of the fishery. As the result, the Thompson and Bell model is more favored than Beverton and Holt yield per recruit model.
To sum up, in this paper, the application, merits, and demerits of the three models have been illustrated using some case studies and data from tropical and temperate fish.

The empirical models were illustrated using the research work conducted in Shahpur Dam, Pakistan, Finnish lakes and raw data from Reyntjens and Tesfaye Wudneh (1998) [17] for some rift valley lakes. Whereas surplus production models were illustrated using the conducted research on Nile perch stock of Lake Chamo (Kassahun Mereke and Bereket Mulugeta, 2016). And lastly the analytical models especially Beverton and Holt model was illustrated using unpublished data on the stock of *Clarias gariepinus* in Lake Hawassa.

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