KENYA MARINE FISHERIES SOCIOECONOMIC DEVELOPMENT PROJECT (KEMFSED) PROJECT

STOCK ASSESSMENT TRAINING WORKSHOP REPORT

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List of Acronyms

BMSY - The biomass that enables a fish stock to deliver the maximum sustainable yield

CMSY - Catch MSY (

CPUE - Catch per unit effort

DIKW - Data-Information-Knowledge-Wisdom

ELEFAN - Electronic Length frequency Analysis

FAO – Food and Agricultural Organisation

FMSY - Fishing pressure that corresponds to maximum sustainable yield

KeFS - Kenya Fisheries Service

KEMFSED - Kenya Marine Fisheries Socioeconomic Development

KMFRI - Kenya Marine Fisheries Research Institute

LBI – Length Based Indicator

LBSPR - Length based spawning potential ratio

LFQ - Length Frequency

SPiCT - Surplus production models in continuous-time

SPR - Spawning potential ratio

TUM - Technical University of Mombasa

UN – United Nations

UNCLOS - United Nations Convention on the Law of the Sea

VBG - von Bertalanffy growth

VMS – Vessel Monitoring System

I. INTRODUCTION

Within the Kenya Marine Fisheries Socioeconomic Development (KEMFSED) Project facilitated by the Government of Kenya jointly with the World Bank, a five-day training workshop on stock assessment was held at Northcoast beach hotel, Kikambala in Mombasa from March 28th until April 1st 2022. The training focused on the purpose of stock assessments, theoretical basis, and hands-on application, including data-limited approaches and related software tools. The training targeted employees of national fisheries, research, and management institutions, professionally involved in collecting and analysing fisheries data.

The training consisted of theoretical concepts and practical application of data-limited assessment tools that allow for the Inference of stock status. It was geared towards revising and updating the knowledge of fisheries theory and assessment methods and providing an opportunity to apply and practice modern stock assessment tools on selected priority species. Thus, the goal was to facilitate the participants to directly use acquired knowledge from the training to improve the performance of national systems. The training constituted of:

1. An introductory part dedicated to Fisheries Statistics
2. Objectives of stock assessment
3. Demonstrations and hands-on practical training and exercises in various data-limited approaches to estimate stock status focusing on
    a. Length based methods
    b. Catch-based and length-based methods.
4. Processing of local data of selected priority species
5. Presentation and reporting on the results of the analyses

Before the training, the potential participants filled out a needs assessment questionnaire to gauge their competency in stock assessment and give an overview of the expectations. Similarly, the participants received a course evaluation form at the end of the training for their feedback.

Summary of participants

The participants for the stock assessment training were drawn from the Kenya Marine Fisheries Research Institute (KMFRI), the Kenya Fisheries Service (KeFS), the County fisheries officers and representatives from the Technical University of Mombasa (TUM) and Pwani University. The participants' details and affiliations are presented in Annex 2 and Table 1. below. The training was attended by 33 participants, 18 males and 15 females.

Table 1: Number of participants in the stock assessment training workshop

Institution	Male	Female
KMFRI	11	10
KeFS	2	3
County Fisheries Office	3	2
Universities	2	-
Total	18	15

Summary of the training needs assessment

Prior to the training, a training needs assessment was shared with the participants to give an impression of their background in stock assessment, their experience and skills in fisheries data handling and their expectations of the course. This information was essential in refining the stock assessment curriculum to align the content to the existing knowledge and competencies of the group. Of all the participants, only 15 were able to complete the survey before the training and the summary is presented in Annex 3 with an extract below.

Overall, all the participants who filled the survey (n=15) had experience collecting fisheries data (100%), 93.3% had competency in analyzing fisheries data, 73.3% had previous training in stock assessment and 86.7% had been involved in some aspects of stock assessment. In addition, 73.3% of the participants had assessed at least one or more species. However, familiarity with the data-limited stock assessment tools and involvement in stock assessment working groups varied, with only 53.3% and 46.7% responding in affirmative, respectively. In terms of their expectations of the stock assessment training, the responses can be broadly grouped into three, as shown below:

1. To improve knowledge in stock assessment

- Estimation of biological reference points
- Interpretation of stock assessment results and application for fishery management
- Reporting of results and development of manuscripts

2. Improved knowledge and awareness of data-limited stock assessment tools
   - Use of R in assessing stock status
   - New packages in R for stock assessment
   - Get a refresher to revise previous knowledge
3. To improve the training of the undergraduate students
   - Analyse students' data
   - Complete manuscripts and thesis

In terms of competency, 71.4% of the participants had an average competency in stock assessment, which indicates theoretical knowledge in stock assessment and the competency to perform stock assessment.

II. KEY OUTPUTS, OUTCOMES AND ACHIEVEMENT

Day 1: Monday, March 28th 2022

1. Why fisheries statistics?

The first training session focused on the less technical aspect of the course, which provided a general overview of fishery statistics and the role of fishery statistics on the national policy, regional management and international level. In particular, the session focused on the critical role of statistics in providing evidence for sustainable fisheries production and management. The need to compile fisheries statistics by individual countries is underpinned by the Code of conduct for responsible fisheries.

> To ensure sustainable management of fisheries and enable social and economic objectives to be achieved, sufficient knowledge of social, economic and institutional factors should be developed through data gathering, analysis and research (Code Art. 7.4.5).

Without good data, fishery policy goals and effective management plans for fisheries cannot be obtained. For an effective policy-making process and assessment and tracking of the performance of responsible fisheries management, fisheries data collection should cover all the different aspects of the fishery, including the natural, social and economic aspects. However, inadequate data, information and statistics often constrain this process.

Fisheries statistics play a crucial role in highlighting the importance of the fishery sector, for instance, to the national food supply, economy, employment, and poverty alleviation. However, these parts of the fishery are often overlooked and are often not well considered in most countries. As a result, only information on the primary output of the fishery exists for most fisheries with no clear idea of all the other aspects.

Many countries, including Kenya, have a system in place to collect fisheries statistics but may be hampered by financial constraints, limiting the scope of data collection to only partial aspects and sometimes taking consideration of only commercial fisheries. Other constraints include the lack of harmonized standards for data collection, leading to non-comparable data or poor documentation and data entry, making them unusable for decision making. Therefore, critical to the collection of fisheries is the ability of a country to collect, produce, analyse and disseminate quality statistics promptly.

Considering all these challenges, fishery management can only be successful if maintained over the longer term at the national level. Management policies must be implemented with good data to promote effective management actions. Therefore, national fishery management institutions need to select and use the appropriate decision-making support tools from various choices. Finding the best tool can sometimes be challenging, given the diversity of options available. Nevertheless, many international instruments can guide countries to promote effective management actions. These include:

- The UN Convention on the law of the sea (UNCLOS)
- UN “Fish Stocks Agreement.”
- The 1994 FAO “Compliance agreement.”
- The FAO code of conduct for responsible fisheries.

1.1. Issues with fisheries data

Data collection is a laborious and expensive process. Hence, it is often frustrating when the data collected are not fully utilised by fisheries managers. Unfortunately, this may be the norm for most fisheries, mainly due to one or several factors, which include:

a) Lack of a clear goal of why the fisheries data are being collected
b) Inability to define the type of data to be collected
c) Lack of accessibility to the data
d) Lack of a proper data validation protocol to assess data quality
e) Failure to compile, analyse and disseminate the data promptly

Other challenges that confront countries regarding fisheries data collection include technical capacity. For example, the people in charge of collecting the data lack the knowledge or are not using appropriate methodologies aligned to the data needs, compromising the process.

Further, there is often a high turnover of staff engaged in collecting and compiling fisheries statistics within institutions. This limits the passing on the vital aspect of the data to the newcomers. This can have serious repercussions when interpreting the results and severe data entry gaps. Other challenges may relate to the multiple reporting obligations where countries must report at different levels, such as the national, regional, or international level, but often not using the same format. These may include:

- Fisheries data collection at the national level to meet the stock assessment needs necessary to conserve and manage fish stocks.
- Socio-economic data to better understand the economic performance and cost implications of the fishery sector
- Collect data to meet regional fisheries management obligations relevant to the conservation and management of shared stocks under national jurisdiction and others beyond national jurisdiction.
- Data needs for reporting to international commitments such as the Sustainable development goal 14 “Life Under Water”.

Successful fisheries management relies heavily on fisheries statistics. Therefore, countries should adopt new and effective ways of collecting data, analysing and disseminating the information in an accurate and timely manner or risk losing the many benefits available from their fisheries resources.

1.2. What data to be collected

The second workshop session focused on the why, what, and how of fisheries data collection. This included elaborating the need for fisheries data collection, an overview of the leading fisheries indicators and variables, and the different collecting methods. Although there are many reasons for collecting fisheries data, data and information are mainly required at three levels:

1) Policy formulation level
2) Formulation of management plans
3) Determination of management actions to implement policy and plans

Policy needs should always drive fisheries data collection. Suppose we have sufficient knowledge about the fisheries. We can formulate better policies for the whole fisheries sector, which might necessitate the collection of an entire array of indicators and variables because multidimensional problems drive the identification of policy priorities and management. The difference between a variable and an indicator is that an indicator may combine the information from one or more variables, e.g. CPUE is derived from two variables, catch and the actual fishing effort.

In most fisheries, data collection takes place without any clear objectives or idea on which indicators or variables should be collected, resulting in waste of resources. Therefore, it is critical that before any data collection is initiated, a clear goal is set on why the data should be collected and what is to be collected. The collection of fishery data is based on a relatively small group of concepts, notably:

a) The exploitation of resources indicators, e.g. catches
b) Fishing operations Indicators, e.g. number of vessels
c) Socio-cultural Indicators, e.g. demographics

d) Economic Indicators
e) Compliance Indicators

When collecting fisheries data, it is crucial to link the indicator on the variable to the required information, which then drives the policy, so the data should always inform and drive the policy. For example, when considering resource exploitation, It is imperative to collect data on the fishing effort and catch production, including some biological data to estimate the maximum sustainable yield, an Indicator for resource exploitation. The operational constraints that determine the choice of variables include:

a) The financial and human capacity
b) The operational characteristics of the fishery that dictate what can be feasibly collected
c) The total number of variables that can be realistically collected
d) The number of Indicators that a variable be obtained
e) How often the that needs to be collected
f) the expected data quality and quantity

In many cases, we are looking for long time series of data to be collected consistently and routinely to evaluate the long-term trends in the behavior of a specific variable. This is particularly key for the stock assessment purposes, and it has been a long-accepted practice with the fisheries data but has been relatively ignored for the economic and social-cultural data. Designing a data collection system by thinking about the indicators and the variables one needs requires a logically structured approach (Fig. 1).

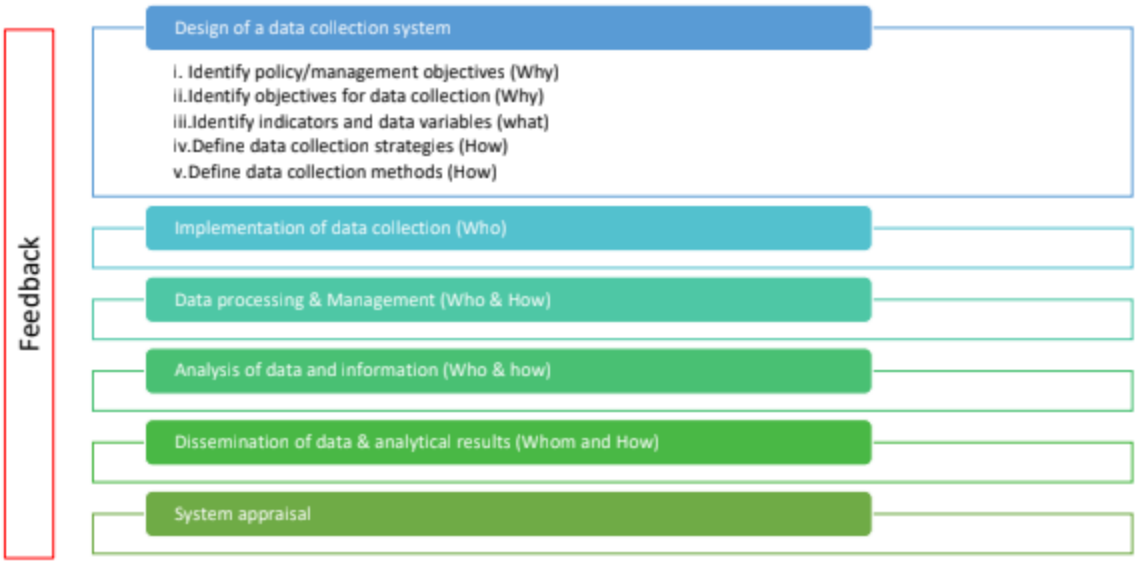

Figure 1: a framework for the data collection process

At the very top of this logical framework is the design of a data collection system identifying the policy management objectives. This is what drives the data collection process. This is then followed by identifying the different stages about what data needs to be collected, how the data will be collected and who should collect the data. This is a logical and structured way to think about the design of a fisheries data collection system, what data is feasible, and the use of the data.

Fisheries data collection is a costly and time-consuming exercise and is strongly influenced by the budget and personnel available. Those are probably two of the most critical factors. The precision required by the data is also dependent on the cooperation of the fishers themselves, which can be a critical factor in data collection. This is particularly the case for coastal, kind of small-scale fisheries where the cooperation and compliance of officials are essential to collect the data. However, from the organizational point of view, budget and staff limitations are still overriding constraints.

Hence, in deciding the indicators and variables be collected, those involved in the fisheries data collection need to go back to basics, set the priorities, and select the essential variables to be collected.

Another critical point to consider is clarifying the purpose of the collected data. When the data's goal is not clear, there is a high possibility of a disconnect between the desired and the generated data. It is important to emphasize that collecting data and information is not an end in itself, but it is essential for informed decision making for management and policy.

1.3. How to produce fisheries statistics

The third session focused on producing fisheries data and the different approaches employed in fisheries data collection. Initially, this consisted of the basic definitions of terms commonly used In fisheries data collection and examples of specific approaches widely employed. As an initial starting point for the importance of fisheries data, the Data-Information-Knowledge-Wisdom (DIKW) pyramid was presented to highlight the progression between data, information, knowledge, and the generation of wisdom. In the fisheries context, the DIKW pyramid shows the importance of fisheries data collection in producing sound policies for sustainably managing fisheries. The pyramid also illustrates the deep relationships and dependencies between the steps involved in the fisheries data collection process, such that bad data will result in insufficient knowledge.

Figure 2: DIKW pyramid

In fisheries, the pyramid can be used to visualize the production of fisheries statistics starting from the type of data to be collected, the data collection process, and the analysis to

generate Information key for policy formulation. The base of the pyramid is the foundation of everything, data collection. Thus, it is critical to the policy formulation that a reliable, efficient, and stable data collection mechanism is in place.

1.3.1. Data collection

The second part of the session highlighted the data collection process. Data collection is collecting information that can be used to find out about a particular subject. This includes gathering and measuring fisheries-related information on targeted variables, enabling fisheries managers to answer relevant policy questions. Data collection is defined by:

- The targeted variables in fisheries - This encompasses fishing and operational indicators, biological indicators, socio-economics indicators
- The established system - Can include small-scale, semi-industrial or industrial fisheries, sales, export or the fisheries sector in its globality

Typically, three types of fisheries data can be collected (table 1). This includes fisheries dependent data related to fishing activities and collected through catch reports, sampled landings, landing site surveys, inspection, frame surveys and observer programmes. The second type of data is fisheries independent data, which includes data collected from scientific surveys. The third type of fisheries data is administrative data collected or managed by institutions related to the fisheries sector (vessel and fisher registries, import/export registries, market prices through surveys, etc.).

Table 2: Essential types of fisheries data

Type	Data collection strategy	Data types (variables/indicators)
Fisheries dependant	Landing site monitoring	Catch Effort (active fishing, gear, number of active vessels) Biological (size, age, sex, maturity, diet) CPUE (calculated)
	Logbooks Catch	Effort (vessel type, active fishing, gear, mesh size CPUE (calculated)
	Observers Catch	Effort (vessel type, active fishing, gear, mesh size Biology(size, age, sex, maturity, diet, genetics, movement/pop structure (tagging) CPUE (calculated)
	Fisher/creel surveys Catch	Effort (vessel type, active fishing, gear, mesh size Biological (size, age, sex, maturity, diet, genetics) CPUE (calculated)
	Market surveys	Biology (size, age, sex, maturity, diet, genetics, movement/pop structure (tagging)
	Frame surveys	Effort (number of fishing vessels, number of fishers)
Fisheries Independent	Scientific surveys/projects	Biology (size, age, sex, maturity, diet, genetics, movement/pop structure (tagging), Abundance

Most countries have a regular data collection system, encompassing routine data collection and surveys/census conducted regularly. For instance, in Kenya, census data is conducted biannually, and it involves the complete fleet, the total population of fishers, and all landings sites through a logbook system. On the other hand, independent surveys are rare and are restricted by financial constraints. Irrespective of which option is selected for data collection, it is essential to ensure that the collected data is stored and processed (micro and macrodata), with their metadata backed up and stored securely. This is a significant step in the data workflow that is often ignored yet serves as an important link when new data are collected or the data corrected, or new algorithms are often available.

Maintaining metadata is vital and should consist of the unit and the methodology for processing the data. Cases of lost or missing data are typical for tropical fisheries primarily because of the inability to properly document and securely store the collected data. This is the most complex and the most complicated step.

1.4. Main Issue In data collection: The case of the Malindi Ungwana Bay Prawn fishery Data

In the afternoon session, the workshop focussed on hands-on examination of real data sets to identify common challenges to the data flow. In the case study, we examined the Malindi-Ungwana Bay observer data. The database contains more than 40,000 entries, with 23 different variables collected through the observer program. From an initial dissection of the data, one is impressed by the sheer volume of data, but on close examination, several issues stand out, which are critical in providing a sound basis for highlighting the common challenges in the fisheries data workflow.

1.4.1. Common data challenges

The first noticeable observation is that there is no metadata to highlight how and what types of data are collected. Why the data was collected and compiled, integrated, summarised, and interpreted. The absence of metadata limits the data users from evaluating the data's accuracy, relevance, and interpretation.

Secondly, the variables are neither consistent nor meaningful. The information that should have been included in the metadata has been embedded in the variable name, resulting in long, unintelligible variable names

On closer examination of the data, there are many data gaps with the key variables collected missing rendering their analysis challenging. For example, missing species names and total lengths of the fish measured renders the entry challenging to be included in stock assessment analysis except to label as NA

Excluding the missing variables reduces the entire data set by half, meaning almost half of the data have missing values.

A closer examination of the remaining variables or entries shows further challenges to the data set. This includes misspelt species names, which leads to a high number of possible species observed. This is also the case with other variable names, such as site, where the misspelling in the variable names results in multiple entries with the same value.

Due to the misalignment of columns, some of the variables appear in the wrong cells. This indicates that cells are copied and pasted from one sheet to another, meaning that the data has been copied multiple times from several databases and pasted onto the final database. Given the volume of data, this can pause a challenging task for the users to examine each entry and make corrections without having proper documentation of the data.

A quick plotting of the dataset with the variable fish size reveals outliers, meaning the sizes entered fall outside the range of the observed fish sizes. From this exercise, it was clear that while much investment has been put in designing and planning the data collection, the final database may be rendered unsuitable if, ultimately, the quality of the data has been compromised during the data entry and this data storage. Hence, it is important that while data collection is a critical step of equal importance, it is the process of entry of, analysis and dissemination. Therefore, one of the ways this can be avoided is to avoid waiting for long before the data is entered and examined.

1.4.2. Data preparation for length-based analysis

The day's final session was spent examining length-frequency data in preparation for the length-based assessment. The participants followed pre-prepared templates to format the data, including identifying the species of interest, reformatting the data and converting the raw length data into bin sizes. This exercise allowed the participants to examine the quality of their data and assess whether the data was meaningful and sufficient sample size for the analysis.

During the exercise, the following observations were made:

i. Lack of consistency in the date formatting. The date entry was not consistent with the excel date format for some of the data.

ii. The entry for fish length has varying units in some data (cm and mm) mixed up. This requires a transformation of the data into a unified format before the analysis
iii. Some of the length-frequency data exceeded the biologically reported sizes for the species.
iv. Data only collected from a single gear or single site
v. Data gaps and lack of consistency in sampling.
vi. The length-frequency histograms have spikes instead of the uniformly distributed histograms

The final part of the last session was spent registering the participants to the Virtual research Environment hosted by the FAO in preparation for the stock assessment exercises.

Day 2: Tuesday March 29th 2022

2. Introduction to stock assessment

2.1. Basics of stock assessment

In the first session of DAY 2, the presentation from the previous day was reviewed, emphasising the importance of fishery statistics, how to produce fisheries statistics, the standard variables and indicators that are collected and the importance of the data workflow. This session also allowed the participants to ask questions that enabled clarifying some of the points from the first day.

The participants were taken through an overview of stock assessment, the events leading from data to advise, specifically the biological processes that drive population dynamics, and data needed to infer stock status and estimate the various components that drive population dynamics.

Stock assessment is a dynamic process involving statistical and mathematical calculations to make quantitative predictions about the response of fish populations to alternative management choices. This includes an estimate of the stock status both in the past and present, projections into the future, and a comparison of stock status to management reference points. In short, stock assessment is an evaluation of various components of the stock equation, including

- Recruitment
- Growth
- Mortality

2.1.1. Recruitment

Recruitment is the conversion of eggs into the fish that reproduce in the next generation. It is among the vital scientific information needed to manage and sustain a fishery. For data-limited fisheries, recruitment estimates are rare and are often computed from other data-rich studies. The goal of the fishery managers is to find the right balance between recruitment and harvest, that is, ensuring that there are enough recruits into the fishery which can grow and mature into an adult population while at the same time maintaining the level of spawners to a level that is sufficient to reproduce recruits into the fishery. As a result, fishery managers use the length at first capture (Lc) as a proxy for the size where 50% of the recruits are under full exploitation.

2.1.2. Growth

This is how individuals grow in size and weight with time. Growth is based on the age and length of structured analytical stock assessment models. The most widely used growth model in fisheries is the von Bertalanffy growth function. One of the critical outputs needed for most stock assessment models is what is commonly referred to as the von Bertalanffy growth parameters (L_{inf} - the asymptotic length, K-the rate by which L_{inf} is approached, and t_0-the theoretical age at zero-length). These values are used as input parameters to estimate the mortality (fishing and natural mortaliy) and exploitation parameters, which indicate the stock status.

2.1.3. Mortality

Mortality rates measure the rate at which fish disappear from a population. When managing exploited populations, the goal is to regulate harvest so that the total mortality rate is below what allows the population to persist. Estimates of the mortality rates are critical for fisheries managers.

The components of mortality rates estimated by stock assessment models often include the total, natural and fishing mortality, respectively. The fishing mortality indicates the impact of fishing on the population, while the natural mortality indicates the number of fish that die out of natural causes. Natural mortality is often the most difficult parameter to estimate in stock assessment. Several methods have been developed to estimate this parameter, each with its level of uncertainty. These are summarised on the barefoot ecologist website.

2.2. Data sources for stock assessment

The second session of day 2 emphasised the data sources needed for stock assessment, specifically the biological variables. In general, there are two data sources for stock assessment:

- Fishery dependent data
- Fishery independent data

Fishery dependent data is primarily derived from the commercial fishing processes. These include:

- Catches and landings: removals, by species, through time (monthly, quarterly)
- Discards (FAO, 2019a) and bycatch (FAO, 2019b): by species, through time (monthly, quarterly …)
- Effort data
- Economic information
- Biological data

In light of the training, this is the most common source of data available for the Kenyan fishery and is compiled through landing sampling, observers program, and the vessel monitoring system (VMS) for the Malindi Ungwana prawn fisheries. On the other hand, fishery-independent data is collected by scientific surveys at sea (e.g. from research vessels) using trawls, acoustic systems, underwater cameras and planktonic egg samplers to gather information on the abundance of the population at sea across the geographic range of the stock.

Given the financial commitments required for conducting independent fisheries surveys, the number and scale of the surveys are restricted in Kenya and are only occasionally conducted, yet they provide unbiased independent indices (relative or absolute) of abundance/biomass at sea. Thus there is a need to develop a strategy of routine independent surveys, at minimum once every five years.

2.2.1. Assessment and management of data-limited fish stocks

Without sufficient data from the fisheries, it is doubtful that the fisheries will be sustainably managed. As a result, fisheries managers should aim to advance in their scope of assessment, with the goal of transiting from a relatively data-poor to data-rich scenario advancing in their analytical and computational complexity while using the best available information to infer stock status. This means selecting stock assessment models based on the data and technical capacity available.

Therefore, fisheries managers and scientists must agree on a set of Performance Indicators, which can be tracked to determine the current state of the fishery relative to the set target. Examples of indicators that can be monitored include

- Exploitation rate
- Spawning potential ratio (SPR)
- Catch trends
- Mean size of the catch
- Catch per unit effort (CPUE)
- Size distribution

During the ensuing discussions, it emerged that this is one of the challenges in the Kenyan fishery, where there are no clear and agreed upon indicators which can be monitored and their performance assessed relative to the targets. As a result, it is challenging to determine what in fishing has changed over time. Therefore, it is important to note that a stock assessment aims to quantify the stock status with reference points and evaluate the effect of different management options. Through this, assessed stocks have a better chance of being sustainably managed. However, data and technical complexities may preclude

specific models and approaches, but this should not be a barrier to assessing stocks. When information is scarce or insufficient in quality, management should increasingly apply precautionary principles to maintain catch and effort at a conservative level until we better understand what is sustainable. When data are not good, empirical indicators and decision rules can be applied to inform management while putting measures in place to collect additional data.

2.3. Introduction to length-based stock assessment methods

As a starting point, length-based assessment methods were explored, and the assumptions behind every method were highlighted in light of the available data and the assessment's primary goal. In this session, the following approaches were explored based on their complexity and data needs, from less data and complexity to more data and more complexity and computation. The methods explored included:

- Length based indicator – in Excel
- Electronic Length frequency Analysis (ELEFAN), implemented in TropFishR
- Length based spawning potential ratio (LBSPR), implemented in the barefoot ecologist web-based shiny app
- Length based indicator (shiny app)

2.3.1. Length based indicator

Studies have shown that high fishing mortality on immature fish has a significant negative effect on stock status. Therefore, to maintain a healthy stock, fisheries managers should put measures to allow fish populations to rebuild and maintain healthy spawning stocks, allowing them to spawn at least once before they are caught. Therefore, to avoid overfishing, the fish in the catch should be larger than the size at which they reach maturity. This is a common indicator used as a proxy for growth overfishing, and the target is to maintain 0% of the catch is < L50. Any value above 0 % indicates overfishing is likely to be occurring. The basic assumptions behind the LBI include:

- Observed data are representative of the catch
- Populations are in equilibrium with stable recruitment & mortality

Using a simple Excel-based template, the participants explored the LBI approach on length-frequency data for specific species selected at the start of the training workshop, with each working group exploring a different species.

2.3.2. Some results of the LBI methods on explored species

The participants were allowed to rapidly assess the length-frequency data from selected species to determine the proportion of catches below the size at maturity.

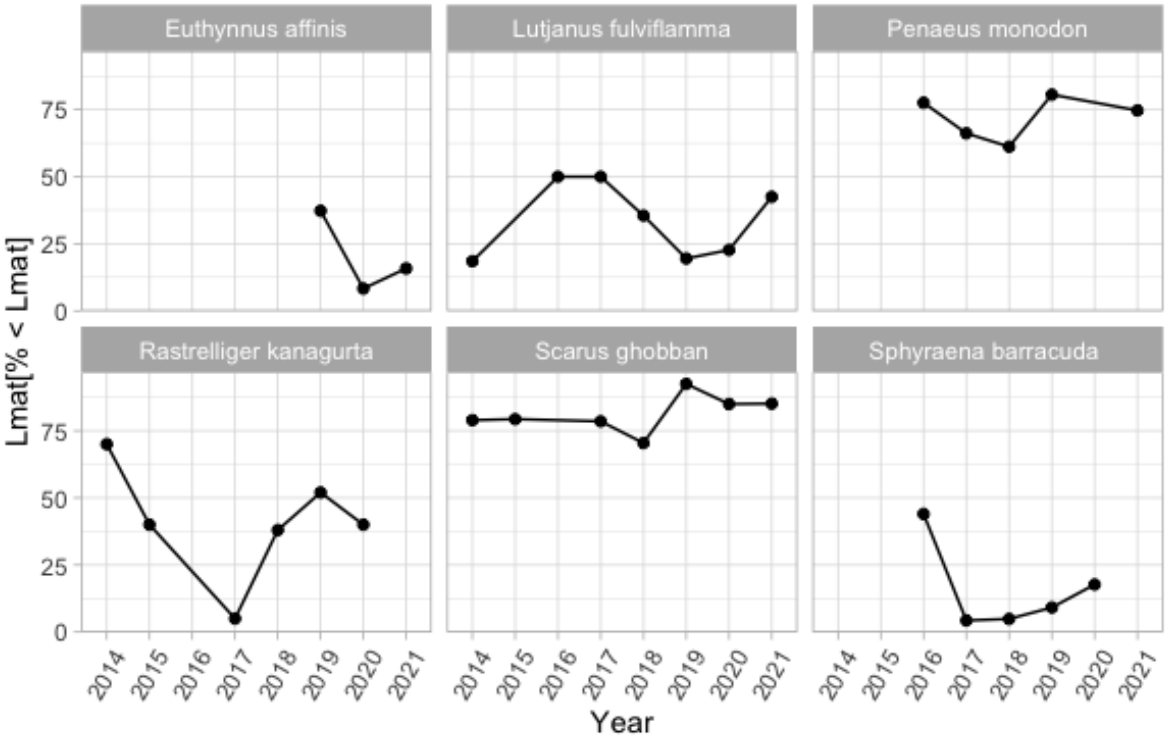

Figure 3: Results of the Excel Length Based Indicator (LBI) applied to six species: *Euthynnus affinis*, *Lutjanus fulviflamma*, *Penaeus monodon*, *Rastrelliger kanagurta*, *scarus ghobban* and *Sphyraena barracuda*

Given that the target for the LBI is to have 0% of all the catches immature, the results from the preliminary assessment of the six species indicate that catches are dominated by immature individuals and an indication of possibly growth overfishing. This means that most of the species are harvested at an average smaller size than the size that would produce the maximum yield per recruit. This was highest for *Scarus ghobban* and *Penaeus monodon*.

Though simplistic in its application, the LBI rapidly assesses the stock's status by giving cues, which are indicators of overexploitation. However, no concrete management decision

can be directly made from the analysis given its subjective nature, particularly when the size at maturity used in the assessment is derived from other studies and not directly estimated from gonad studies of the primary species. In addition, the sharp interannual variations observed in some of the species may be an artefact of undersampling or selective sampling from specific gears, which would undermine one of the assumptions of having a catch representative of the population. Hence, a more extended time series would be required to observe and make realistic conclusions.

Day 3: Wednesday March 30th 2022

2.3.3. Electronic Length frequency Analysis (ELEFAN)

The participants had the opportunity to apply the updated version of the Electronic Length frequency Analysis (ELEFAN), implemented in TropFishR), an R based shiny app that allows for the estimation of growth parameters of fish by fitting based on the von Bertalanffy Growth Formula (VBGF). The availability of growth parameters (mainly Linf and K) is key to applying most length-based stock assessment methods, which require these parameters as input. The TropFish based ELEFAN is an updated version, which allows for flexible restructuring, fast and objective optimisation and has the option for performing the seasonalised von Bertalanffy option.

Some of the assumptions for the ELEFAN routine include:

- The samples are representative of the population exploited
- The growth pattern is the same from year to year
- The growth of the species conforms to the von Bertalanffy growth equation
- Constant recruitment and mortality

Before running the analysis, the participants were guided through the data preparation stages, which include:

- The aggregation of samples by date
- Binning of the length frequency based on optimum bin size
- Reformatting the length-frequency into mid-length and dates by the number of individuals per bin size.

2.3.4. Results of the ELEFAN on explored species

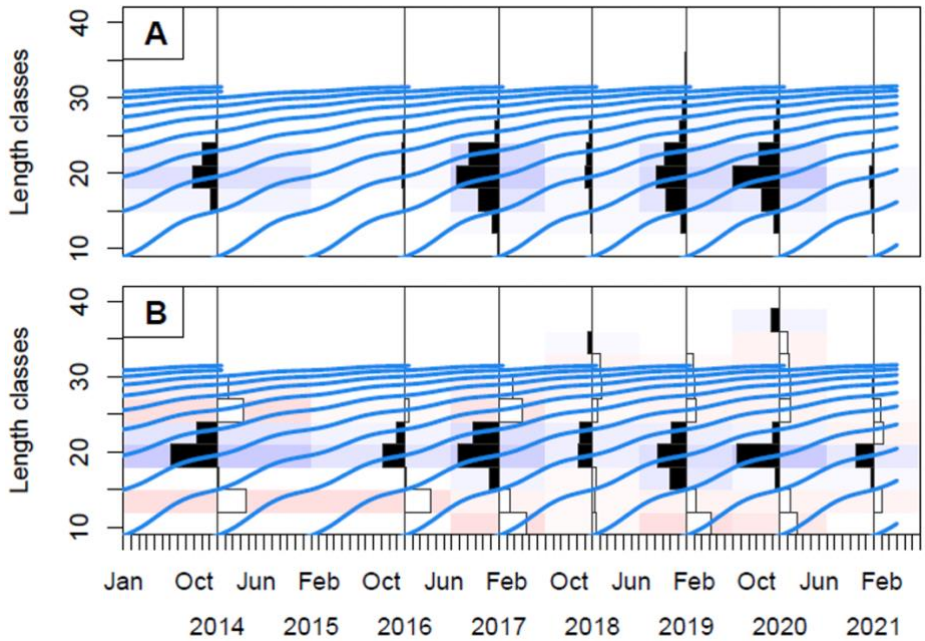

Figure 4: Uploaded raw (A) and restructured (B) length-frequency data for the Lutjanus fulviflamma overlaid with the von Bertalanffy growth (VBG) curves fitted by ELEFAN with genetic algorithm

Table 3: Summary of the ELEFAN results of selected species, with estimated growth parameters and indicator of stock status

Species	No. of yrs	K	Linf	Rn score	M	F	E	Status	Comments
Lutjanus fulvifalmma	8	0.28	33.3	0.05	0.74	0.41	0.35	E < 0.5	Poor fit to the model, M > F is unrealistic
Euthynnus affinis	2	0.39	102	0.32	0.45	1.56	0.77	E > 0.5	Poor fit to the model
Thunnus albacares	4	0.37	192		0.19	0.1	0.34	E < 0.5	Poor fit to the model, M > F is unrealistic
Scarus ghobban	8	0.26	69.1	0.27	0.57	1.59	0.21	E < 0.5	Poor fit to the model
Metapenaeus monoceros	6	0.22	78.5	0.58	0.33	0.42	0.56	E > 0.5	K unrealistically low
Otolithes ruber	4	0.17	49.8	0.30	0.31	0.42	0.57	E > 0.5	K unrealistically low

The results of the ELEFAN routine on the selected species revealed some of the data weaknesses, which are linked to the sampling of the length data, which may lead to biased estimates of the growth parameters. These include:

- The underrepresentation of the larger individuals in the sample may be an artefact of the sampling regime, either focusing on select gears or sampling from fishers from specific areas.
- Small sample size per month despite having a long time series of more than three years for each species

- Unbalanced sampling, with gaps between the sampling periods, leads to a poor fit of the model resulting in low Rn scores

As a result, some of the estimates, such as K and M, were unrealistically low or high, given that the proportion of individuals assessed represents a portion of the population with high growth rates, such as juveniles. This highlights the need to properly design the sampling regime to ensure that enough samples representing the exploited population are sampled across all fishing gears.

2.3.5. Length based spawning potential ratio

The length-based spawning potential ratio (LBSPR) is based on the concept that a fish population can complete 100% of its natural spawning potential without fishing, but that fishing reduces this potential. The method assesses the effect of fishing by measuring how fishing impacts spawning potential. The SPR is calculated as an index representing the proportion of reproductive potential at current fishing levels relative to unfished levels. The SPR indicates relative fishing pressure (F/M) and is an internationally recognised reference in fisheries management. Key outputs from the LBSPR include:

- F/M (fishing mortality rate/natural mortality rate)
    - A relative measure of fishing levels
    - The general rule of thumb is that FMSY ~ 0.8-1.0 x M
- Size at 50 % and 95 % selectivity

Data requirements for the method include:

- Length data
- Estimates of L50 and L95 (50 % and 95 % maturity)
- Life history ratios:
    - Natural mortality/von Bertalanffy growth rate (M/k)
    - Relative size at maturity (L50/Linf)
    - The absolute measure of Linf

2.3.6. Results of the LBSPR on explored species

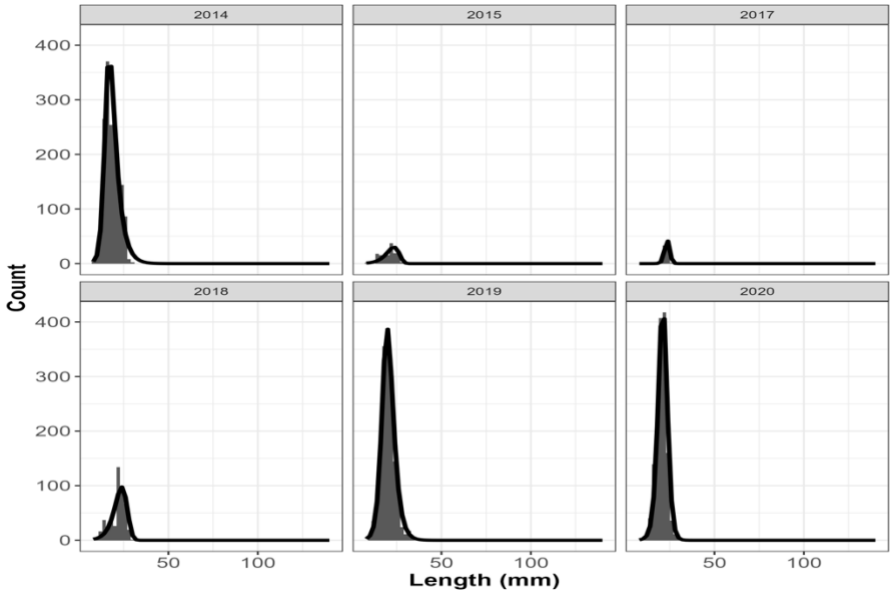

Figure 5: Length composition distributions for *Rastrelliger kanagurta* with curves fitted by length based SPR assessment software.

The model fit on the LFQ data clearly shows that there was undersampling in 2015, 2017 and 2018 due to the sampling design. In addition, the size-frequency distribution is unimodal with a skew to the right and an indication of selective sampling of smaller individuals. Clearly, with such a distribution, the data violates the basic assumption of catch representing the exploited population, given that there are no large-sized individuals in the sample.

The estimated maturity and selectivity curve for the two selected species (*Metapenaeus monoceros* and the combined Octopus species) reveal a poor fit, associated with the input parameters for the length at first maturity (L50 & L95). Most of the species assessed did not have primary input biological parameters estimated directly from the species but relied on secondary estimates of similar species from other geographic areas. For most species, the estimated SPR value fell below the 40% target, which is the proxy for BMSY and indicates that the fishery may be prone to overfishing based on these results.

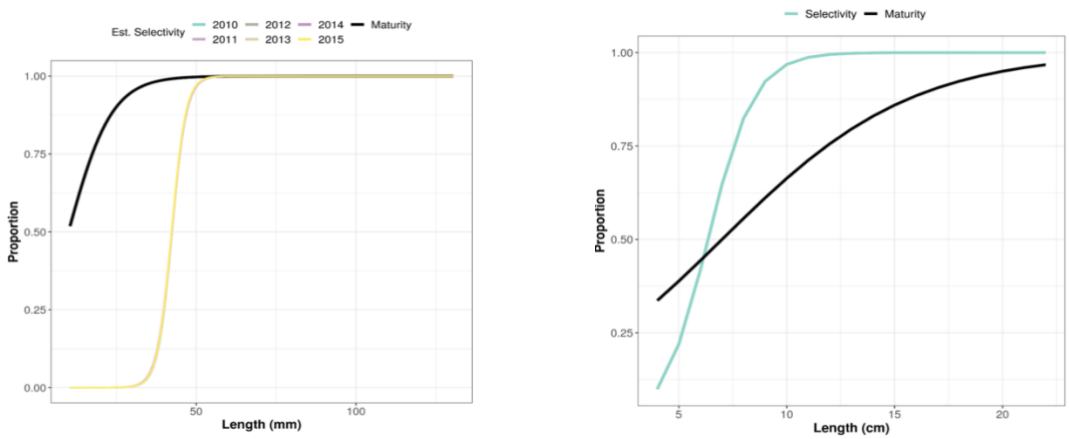

Figure 6: Maturity at length and the selectivity at length curves for the Metapenaeus monoceros (left) and the combined Octopus species (right)

2.3.7. Length based indicator shiny

Length-based indicator is a data-limited tool used to screen length composition data and classify the stocks according to conservation/sustainability, yield optimisation, and MSY considerations (Table 3). LBI requires data on length composition and life-history parameters to determine fishing mortality to MSY. The LBI is increasingly being applied to data-limited stock and is considered more robust than the length-based approaches when there is a high level of uncertainity in estimating growth parameters (Linf). LBI assumes equilibrium conditions (total mortality and recruitment) over the lifetime of the time series and a logistic selectivity.

Table 4: Summary of the LBI Indicator and Interpretation

Indicator	Calculation	Reference point	Indicator ratio	Expected value	Property
$L_{max5\%}$	Mean length of largest 5%	L_{inf}	$L_{max5\%}$ / L_{inf}	> 0.8	Conservation (large individuals)
$L_{95\%}$	95th percentile		$L_{95\%}$ / L_{inf}		
P_{mega}	Proportion of individuals above L_{opt} + 10%	0.3–0.4	Pmega	> 0.3	
$L_{25\%}$	25th percentile of length distribution	L_{mat}	$L_{25\%}$ / L_{mat}	> 1	Conservation (immatures)
L_c	Length at first catch (length at 50% of mode)	L_{mat}	L_c/L_{mat}	> 1	
L_{mean}	Mean length of individuals > L_c	N	L_{mean}/L_{opt}	≈ 1	Optimal yield
L_{max_y}	Length class with maximum biomass in catch	$L_{opt} = \frac{3}{3+ M/_k} \times L_{inf}$	L_{maxy} / L_{opt}	≈1	
L_{mean}	Mean length of individuals > L_c	$L_{F=M}$ = $(0.75L_c+0.25L_{inf})$	L_{mean} / $L_{F=M}$	≥ 1	MSY

2.3.8. LBI results of selected species

After applying the LBI to the time series length-frequency data, the results of selected species were compared based on the target reference points, summarised in a colour-coded table (table 4). The green colour means that the indicator ratios of the corresponding property are above their expected reference points, while red denotes that the indicator ratios are below the target reference points.

Table 5: Results of the LBI analysis for selected species for the year 2020

Species	Year	Conservation				Optimising Yield	MSY
		L_c / L_{mat}	$L_{25\%}$ / L_{mat}	$L_{max\ 5}$ / L_{inf}	P_{mega}	L_{mean} / L_{opt}	L_{mean} / $L_{F=M}$
Scarus ghobban	2020	0.34	0.44	1.09	0.18	0.65	1.16
Lutjanus fulviflamma	2020	0.96	0.96	1.11	0.31	1.09	0.99
Metapenaeus monoceros	2020	0.15	0.15	1.53	0.33	0.88	2.16
Otolithes ruber	2020	0.87	0.87	0.85	0.1	0.91	0.98
Sphyraena barracuda	2020	0.21	0.22	0.25	0	0.23	0.46

Based on the summary of the 2020 results for the five selected species, the results indicate that all the species are targeted below their size at maturity, indicating growth overfishing. The target to conserve mega spawners is variable among the species, similar to that of maintaining fishing above the MSY. The method showed great promise for most of the species. However, it was evident that the precision of the estimates of the life history parameters is critical in determining robust results. This calls for a more representative size composition data to include all the possible spatial and seasonal coverage.

Day 4: Thursday March 31st 2022

3. Catch based methods

On the fourth day, the participants were taken through the catch based assessment methods focusing on the CMSY and the SPiCT, both surplus production models. At first, a general background was given on the Law of the Sea (UNCLOS 1982), which requires signatory countries to maintain fish stocks such that their stock size (B = biomass) is large enough to produce the maximum sustainable yield (MSY). Thus the reference for sustainable fisheries management is the MSY, and countries should aim to manage their fisheries based on the

MSY. However, given the challenge of estimating MSY and the fact that most fisheries remain data limited, it is essential to adopt tools that can estimate MSY even with limited data.

Data-poor models work with the typically available data, such as time series of catch or abundance indicators (CPUE) or length-frequencies and they combine available data with independent knowledge (= priors) to estimate the MSY. However, despite their capabilities, it is still to note that the resulting outputs will largely be influenced by the type of input data and initial priors. The participants were then taken through the background of the surplus production models and the evolution from the initial Malthusian equation by Thomas Robert Malthus to the logistic equation by Pierre François Verhulst and finally, Milner Baily Schaefer, who applied it to fisheries and introduced the idea of the MSY.

In this session, the participants were introduced to the CMSY approach, which takes as input, catch data a prior for resilience (r) and a broad range of priors of biomass to unfished biomass (B/k) to estimate fisheries reference points (MSY, Fmsy, Bmsy) as well as relative stock status (B/Bmsy9 and the fishing pressure (F/Fmsy).

3.1. CMSY results of selected species

Given that most of the data used in the exercise were not to the species resolution, the results of the CMSY were taken to be only indicative. For example, Figure 7 presents the summary results of the parrotfish, which is a combination of all the parrotfish targeted in the Kenyan waters.

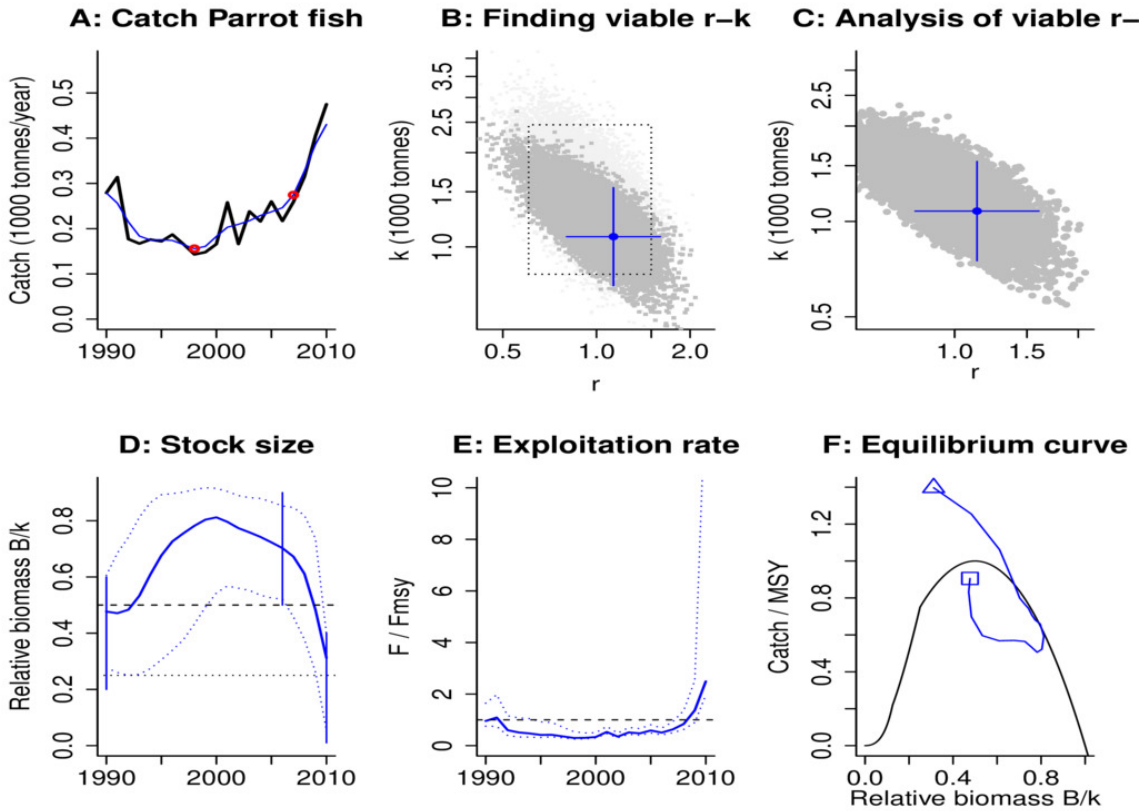

Figure 7: Results of the CMSY stock assessment for the parrotfish(combined species based on total landings reported in the annual fisheries bulletin for 1990-2010. Upper left panel: A: Catch; B-C: panels identifying viable r-k pairs, with estimates of r = 1.13 (0.801-1.6), k = 1.8 (0.752-1.55); D: biomass trajectory and the exploitation rate (E) and obtaining (in F) an estimate of MSY = 308 tonnes·year^{-1} (223-410).

The resulting CMSY analysis came up with nearly 41,898 viable trajectories for 12303 r-k pairs, with r = 1.13 (0.801- 1.6) and k = 1.08 (0.752-1.55) providing an estimate of MSY = 308 tonnes year-1 (0.233-0.41), and a relative biomass (B/k) in 2020 of 0.312, with and exploitation (F/(r/2) of 2.49, resulting in a B/BMSY = 0.624 and F/FMSY = 2.49. Figure 7 presents the results of the analysis.

Applying CMSY to aggregated data may pause several challenges, such as species having different r values. Thus, the lumping of species makes sense only if they are caught together and have similar r values and act as a functional guild. In addition, their biomass should show the same response to increase or decrease in the catch. If this is not the case, then joint management makes no sense.

Day 5: Friday April 1st 2022

4. Final presentations and recommendations

The fifth day of the workshop was dedicated to finalising the analysis and preparation for group work presentations. The participants worked in five groups on selected data sets on key species to infer the stock status (+ biological and fisheries parameters) employing introduced length-based and catch-based methods. Based on the individual group work presentations and ensuing discussions, it is evident that there is scope to apply current data-limited assessment models to the Kenyan marine fisheries. However, these approaches rely heavily on biological parameter estimates, which may be biased when samples are taken from a fishery already subjected to heavy fishing and may be constrained by the lack of historical data in the catch-based methods. In the final group work presentations, the following observations were made:

1. Despite having time-series data on length-frequency (2-5 years), the data fit the existing models was poor, especially for ELEFAN and LBSPR (low Rn scores & poor fit to LFQ). This can be linked to:
    - Undersampling, having insufficient samples to trace the cohorts of time
    - Lack of clearly defined cohorts in the LFQ
    - Skewed LFQ highlights smaller individuals' dominance and the absence of larger individuals in the sample.
    - A bimodal distribution in the size structure is represented by juveniles and adults rather than a unimodal distribution.
    - Biased sampling from specific gears leads to the skewed size distribution
    - Absence of data in some months leaving huge gaps between samples
    - Combining long time series for short-lived species or aggregating of data.

The effect of sample size can lead to variability and bias in estimating growth parameters.

2. All the length-based assessment methods required some biological paramters such as maturity and natural mortality as input. Unfortunately, most of the species lack

biological parameters, and as such, the parameters were estimated from secondary sources, e.g. Fishbase or well-studied stocks. This introduces some level of bias due to the uncertainty associated with these parameter estimates, resulting in:

- Unrealistic selectivity patterns (LBSPR)
- Unrealistically high F/M ratios (LBSPR)
- under-estimation of SPR (LBSPR)
- Inability to accurately estimate reference points

3. For catch based method (CMSY), a minimum of 10 continuous years of catch data is required. This is missing for most species.
4. In cases where long time series data exist, the data is aggregated at the family level, making it challenging to estimate the initial priors needed as input parameters.

5. Recommendations and conclusion

- Proper measures must be put in place before data collection starts to ensure harmonisation among the working groups. Preferably, the following aspects should be included in each research strategy:
  - The type of data to be collected and over what period
  - For what purpose the data is being collected
  - Harmonisation with county fisheries data collection.
- Design an appropriate sampling regime with the stock assessment tools in mind, considering the sample size, assumptions and limitations of the method.
  - The assessment tools to be applied and the expected results
  - Assumptions of the methods and the data requirements for each method proposed
- Put a data management protocol for the KEMFSED project to assist in describing critical aspects of data handling in a structured manner. This should take into consideration:
  - Data description: how the project will generate data and if existing data will be reused and the anticipated data volume

    - Documentation of data (metadata) and the quality checks to be verified
    - How the data will be stored and accessed during the project duration
    - Data exchange: which criteria will be used to make data available for subsequent use.
    - Who is responsible for data handling and responsibilities within the project
- Check the validity of the data during data entry and before running the assessment to ensure the accuracy, consistency and quality of data.
    - If the data will be entered in excel, use validated sheets to restrict entries
    - Data entry and visualisation should be a continuous process to allow for quick and easy checks and to rectify any errors promptly
- More emphasis should be put on sampling biological data (maturity estimates) for the priority species to allow a more realistic estimation of growth parameters.
- Close linkages between the research institutions and the universities to fill in the gaps in data through student projects linked to the priority species.
- Continuous stock assessment training focuses on having at least two pieces of training annually. This should be conducted closely with universities to allow for sustainability and evaluation of the participants in a structured manner.
- Annual stock assessment reports should be updated to reflect the improved competency and tools introduced during the training.
- Training should also target county fisheries officers.

Annex 1: AGENDA

Time	Day 1:
08:30 – 09:00	Registration of participants
09:00 – 09:30	Welcome and opening of the workshop - Official opening statement - Self-Introduction of participants - Opening statements from - Presentation of agenda and workshop objectives
09:30 – 10:30	Why fisheries statistics? - Overview - Role of statistics - Statistics in support of evidence-based national policy-making: stock assessment - Statistics in support of fisheries management decisions - Statistics in support of international fisheries management
10:30 – 11:00	Group Photo /Refreshment break
11:00 – 12:30	What data is to be collected for which fisheries statistics? - Why what and how of fisheries data collection? - Why do we collect fisheries data? - Definition: variables and indicators - Examples of fisheries variables and indicators - Data collection methods: summary - Determining which indicators/variables from which data - Fisheries indicators: key points
12:30 – 13:30	Lunch
14:00 – 15:00	How to produce fisheries statistics - From data collection to Fisheries Statistics - Need for reporting: according to standards - Need for stock assessment process: different models depending on availability of data and statistics - Data policies: security of data, confidentiality, data access and data sharing
15:00-16:00	Practical Exercises
16:00 – 16:30	Refreshment break
16:30 – 17:00	- General discussion on data collection system gaps and recommendations and continuation of exercises
	Day 2:

09:00 – 09:15	Overview of Day 1 and feedback on pending questions
09:15 – 10:30	Introduction to Stock assessment - Basics of stock assessment and reference points - Objectives of stock assessment - Data for stock assessment - Biological data and Stock assessment - Common methodological and operational characteristics - Determining the right tool for assessment
10:30 – 11:00	Refreshment break
10:30 – 13:00	Practical Exercises - Examining data quality and determining appropriate tools for assessment - Assessment and management of data-limited fish stocks - General intro to length-based method and overview of length-data
13:00 – 14:00	Lunch
14:00 – 16:00	Length-based methods - Length-based indicator (LBI) and LBSPR method overview - overview of method theory - Assumptions; - data requirements; - overview of method workflow Sample dataset/diverse case studies - data formatting rules; - loading data into spreadsheet tool; - input data, advice for best practice; - outputs & interpretation of results - Hands-on work (LBI and LBSPR)
16:00 – 16:30	Refreshment break
16:30 – 17:30	- Additional supported analysis
	Day 3:
09:00 – 10:30	Continuation of Length-based methods - Estimating biological parameters - Elefan/YPR overview of method theory - Hands-on exercise with real data
10:30 – 11:00	Refreshment break
11:00 – 12:30	- Hands-on practical work with real data in groups
13:00 – 14:00	Lunch break

14:00 – 16:00	- Estimating fishing mortality & reference points, and stock status (presentation) - Hands-on practical with actual data and presentation of results (all groups will work on the priority species and have the results presented by the end of the session).
16:00 – 16:30	Refreshment break
16:30 – 17:00	- Analysing example data (hands-on) (presentation)
	Day 4
09:00 – 10:30	Introduction to Catch Based stock assessment methods - Introduction to CMSY and SPiCT - Theory, assumptions and data requirements - Introduction to SMT - CMSY - Data formatting - Hands-on application
10:30 – 11:00	Refreshment break
11:00 – 13:00	- Hands-on practice with real data
13:00 – 14:00	Lunch break
14:00 – 16:00	- Mini project (groups work on priority fish stock with data)
16:00 – 16:30	Refreshment break
16:30 – 17:00	- Mini project (groups work on priority fish stock with data) - Discussions and recommendations on online tools
	Day 5:
09:00 – 10:30	- Mini project (groups work on priority fish stock with data)
10:30 – 11:00	Refreshment break
11:00 – 13:00	- Mini project - summarising the results from the analysis based on data for priority species - presentations
13:00 – 14:00	Lunch
14:00 – 16:00	- Mini project presentations

16:00 – 16:30	Refreshment break
16:30 – 17:00	- Evaluation and Feedback - Closing ceremony

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Annex 3: NEEDS ASSESSMENT

1. Do you have experience in:

i. fisheries data collection
ii. analysing fisheries data?
iii. stock assessment and
iv. participation in previous stock assessment training

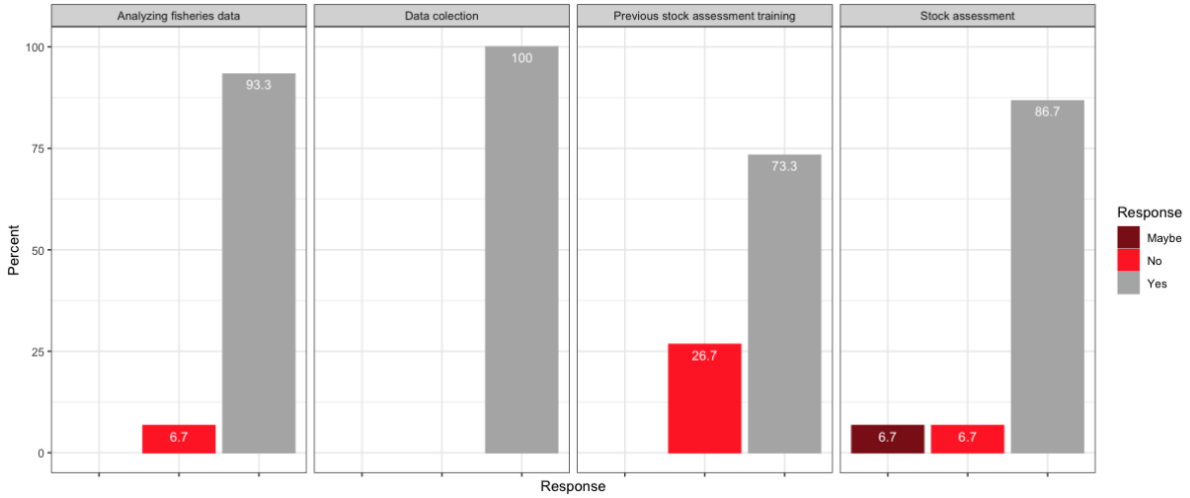

Figure 8: Participants' responses to the question of having experience in (i) analysing fisheries data, (ii) fisheries data collection, (iii) being involved in stock assessment and (iv) participation in previous stock assessment training.

2. Have you performed a stock assessment yourself?

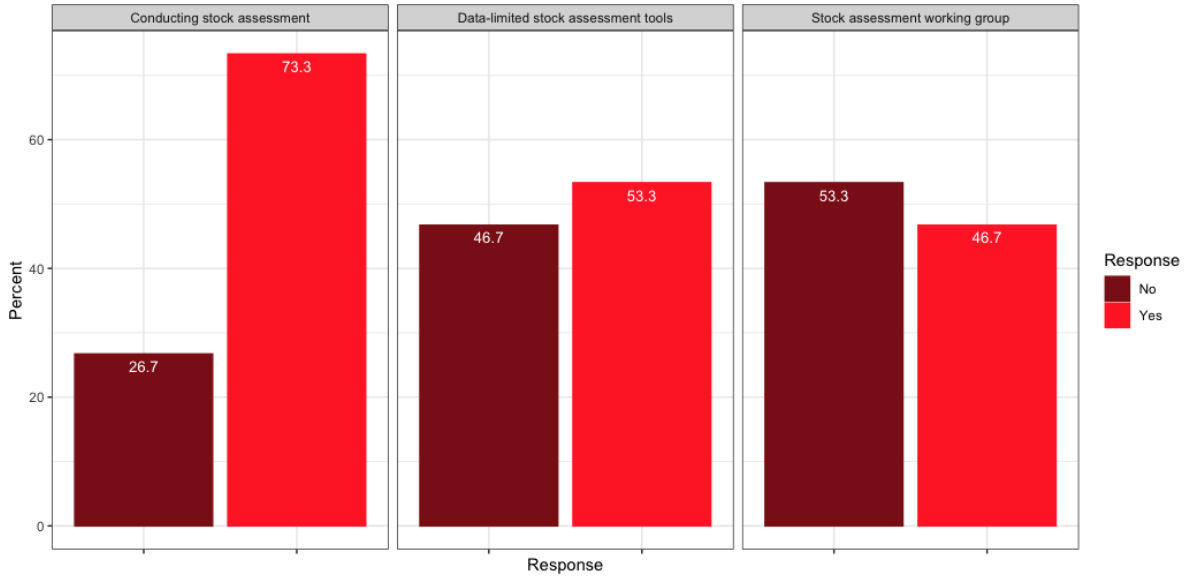

Figure 9: Participants' responses to the questions: do you have experience in (i) conducting stock assessment, (ii) data-limited stock assessment tools, and (iii) involvement in stock assessment working group.

3. **What is your level of experience in stock assessment on a scale of 1-5, where 5 is the highest?**

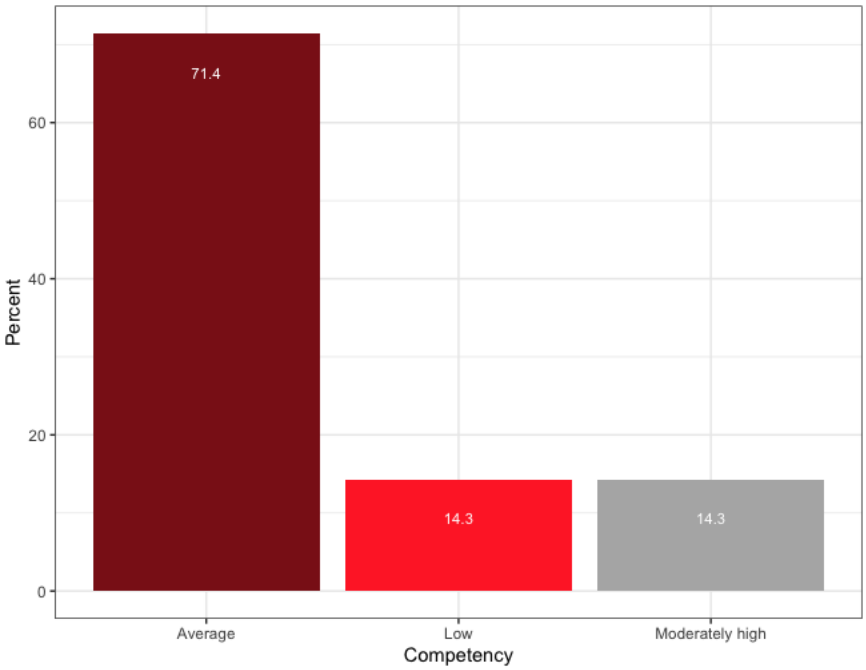

Figure 10: Participants' level of competency in stock assessment on a scale of 1-5 (1=No competency, 2 = low competency, 3= average competency, 4= Moderately high competency and 5 = high competency)

Annex 4: COURSE EVALUATION

1. Overall, were you satisfied with the venue of the stock assessment training?

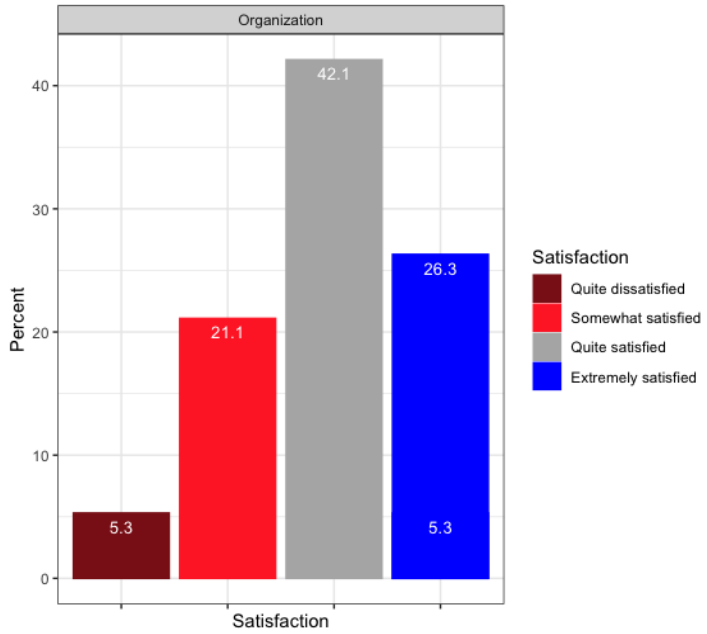

Figure 11: Participants' responses on their satisfaction with the workshop venue

2. Which aspects of the venue were you satisfied or dissatisfied with?

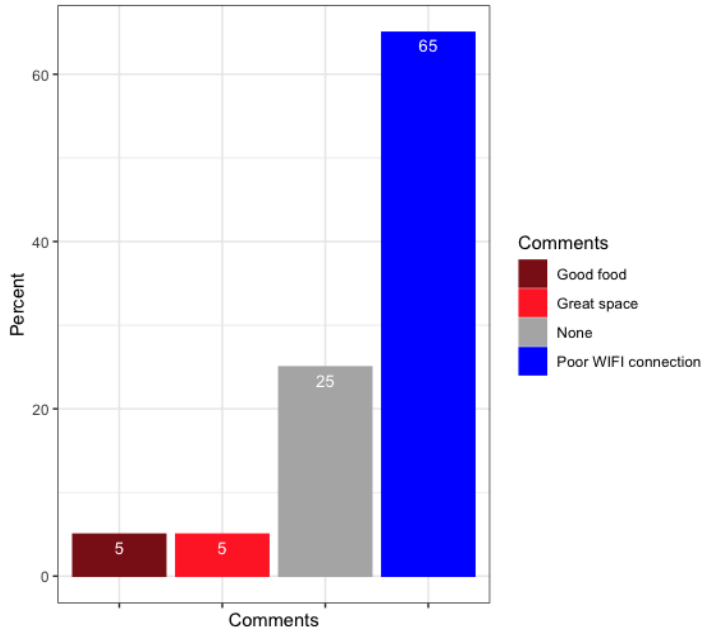

Figure 12: Participants comments on their satisfaction or dissatisfaction with the workshop venue

3. Please rate how valuable these presentations/sessions were

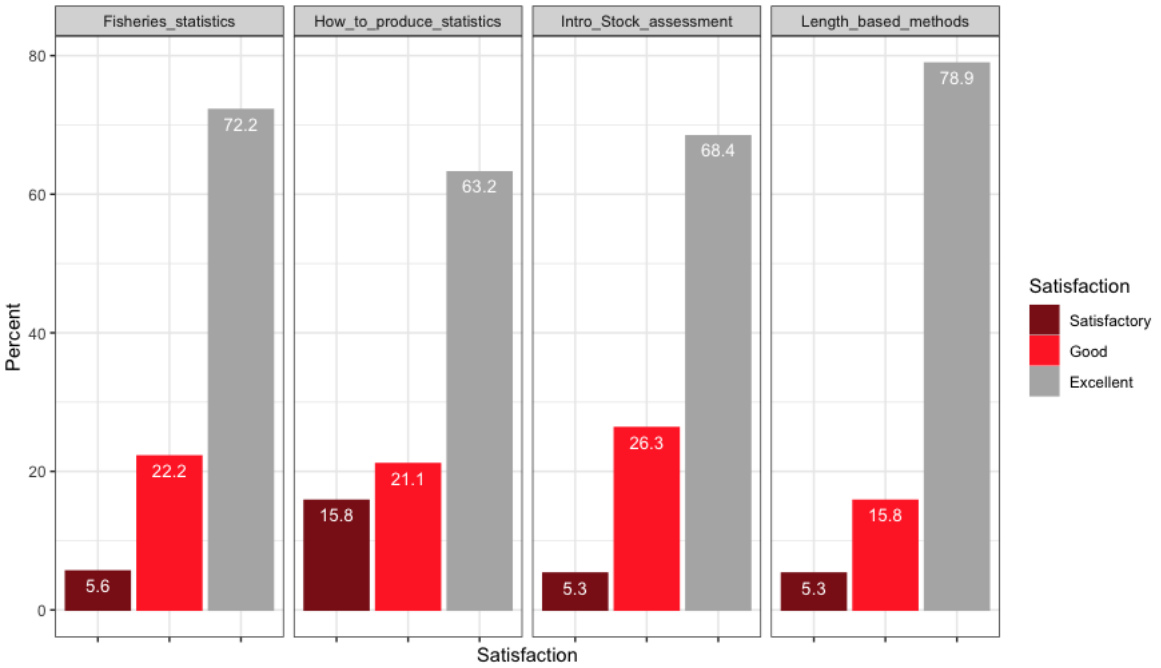

Figure 13: Participants' responses to specific aspects of the course content: (i) role of fisheries statistics, (ii) how to produce statistics, (iii) introduction to stock assessment and (iv) length-based stock assessment methods

4. Please rate how valuable these presentations/sessions were

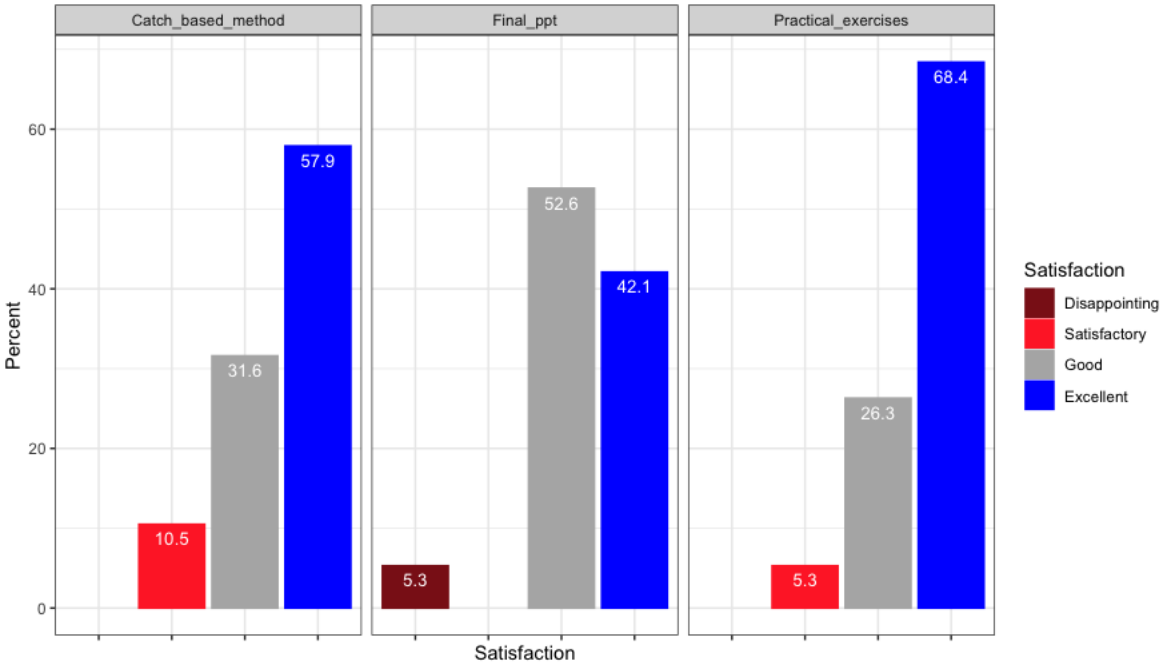

Figure 14: Participants' responses to specific aspects of the course content: (i) catch based method, (ii) final participants' presentation and (iv) practical exercises

5. **What was your general assessment of the following areas of the workshop?**

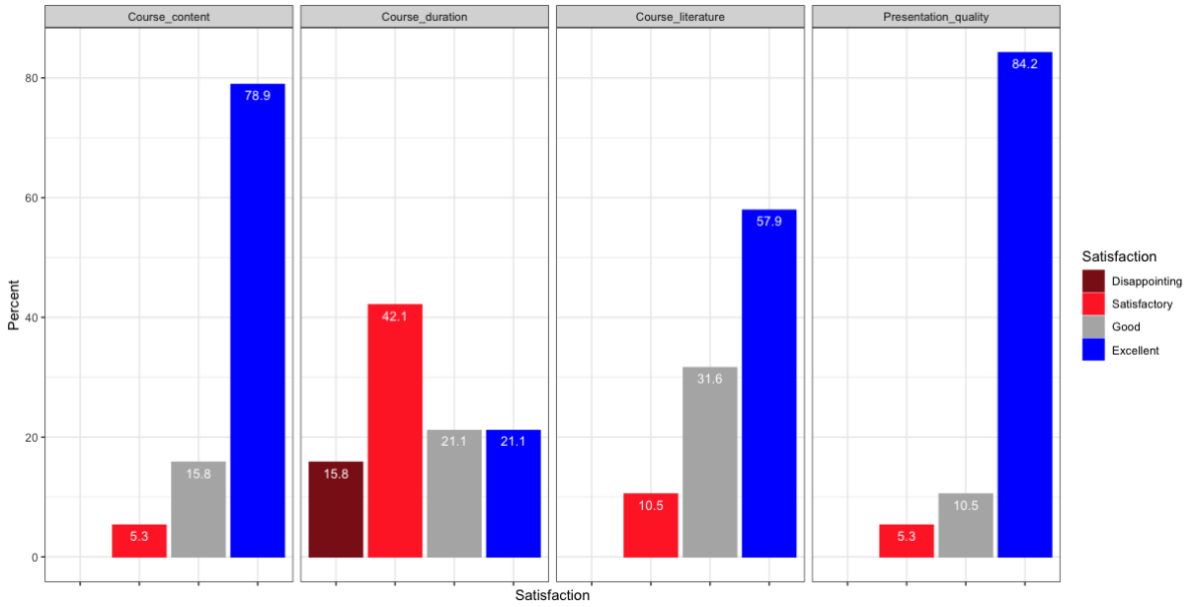

Figure 15: Participants' responses to specific aspects of the training: (i) course content, (ii) course duration, (iii) course literature and (iv) presentation quality

6. **How helpful were the following tools in analysing your dataset?**

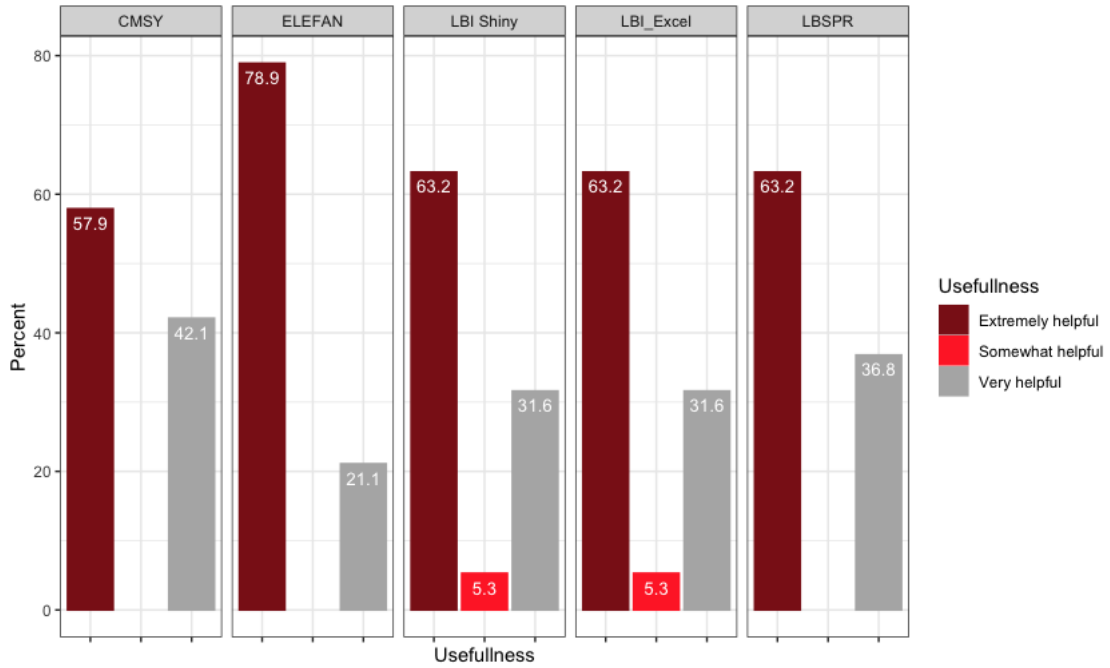

Figure 16: Participants' responses to the usefulness of the stock assessment tools in analysing their data: (i) CMSY, (ii) ELEFAN, (iii) LBI shiny, (iv) LBI excel and (iv) LBSPR

7. **Overall how satisfied were you with the instructor who led the training? Select an answer for each question provided.**

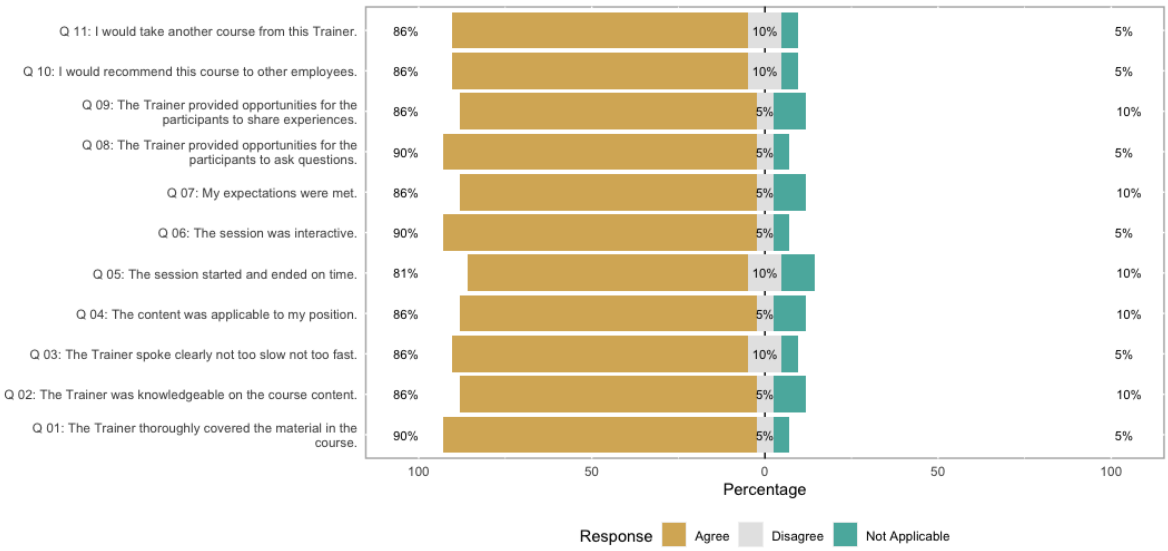

Figure 17: Participants' feedback on the trainer's competency and delivery